TR-3189

AD-A234 255

TECHNICAL REPORT BRL-TR-3189

BRL

A NEW HIGH-PROGRESSIVITY/ HIGH-DENSITY PROPULSION CONCEPT: PARTIALLY CUT MULTIPERFORATED STICK PROPELLANT

CARL R. RUTH
FREDERICK W. ROBBINS
THOMAS C. MINOR
ARTHUR A. KOSZORU

MARCH 1991

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

NOTICES

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1991	Final Jan 87 - Oct 87

4. TITLE AND SUBTITLE

A New High-Progressivity/High-Density Propulsion Concept: Partially Cut Multiperforated Stick Propellant

5. FUNDING NUMBERS

P: 1L162618AH80

6. AUTHOR(S)

Carl R. Ruth, Frederick W. Robbins, Thomas C. Minor and Arthur A. Koszoru

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

USA Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

BRL-TR-3189

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for Public Release - Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This report presents the results from investigations with a high-progressivity/high-density (HPD) propelling charge concept using partially-cut, multiperforated stick propellant. While multiperforated stick propellant is attractive both for its progressivity and loading density, the internal pressurization of the long, unvented perforations is of considerable concern. Such internal pressurization may result in mechanical failure of the grains, exposing unprogrammed burning surfaces and leading to overpressurization of the chamber. In the partially cut configuration, the perforations are vented via cuts made through the perforations perpendicular to the axis of the grain at periodic locations along the axis. In order for the partial cutting to be effective, the spacing of the cuts must take into account the diameter of the perforation and the burning rate of the propellant in the perforation.

Described in the report are the design of the apparatus for partially cutting the propellant grains, the cutting and loading procedures for the charges, and the experimental firing results. Firings were conducted with two lots of JA2 propellant at ambient temperature in a 155-mm, M199 cannon ported to measure pressures at numerous axial positions along its length. A comparison of the results from the partially cut stick propellant with those from the baseline top-zone artillery charge for the 155-mm howitzer demonstrated an increase in muzzle velocity at equivalent pressures.

14. SUBJECT TERMS

Interior Ballistics, [illegible] Pressure, 155-mm Howitzer, Pressure Measurements, Propellants

15. NUMBER OF PAGES

52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

INTENTIONALLY LEFT BLANK.

LIST OF FIGURES

INTENTIONALLY LEFT BLANK.

LIST OF TABLES

INTENTIONALLY LEFT BLANK.

1. INTRODUCTION

Development of a Zone 8 propelling charge for the Army 155-mm howitzer has gone through numerous iterations over the past several years. Earlier versions of the M203, Zone 8 charge did, on occasion, have excessive pressures and even breechblows associated with large-amplitude pressure waves. The excessive pressures are believed to have resulted from improper ignition of the main granular centercore-ignited propellant charge.[1,2] As shown in Figure 1, the presence or the absence of pressure waves in gun chambers could be readily apparent upon examination of multi-station, pressure-time data or the difference signal between two such pressure stations. Other investigators[3-6] have suggested that the use of 19-perforation propellant grains and/or modifications to the 7-perforation configuration, as well as improved centercore ignition design, would result in a propelling charge more forgiving to less-than-optimum ignition conditions, thereby reducing the occurrence of high-amplitude waves and associated problems. Specific benefits in using the 19-perforation propellant are: (1) increased velocity, (2) less round-to-round variability in pressure waves and (3) expected lower nominal pressure-wave levels . The studies suggested that the responsible mechanisms were the reduction in initial surface area and the increase in bed permeability to igniter and initial propellant gas flow through the charge. Both factors tend to mitigate the formation of locally high pressures in the chamber.

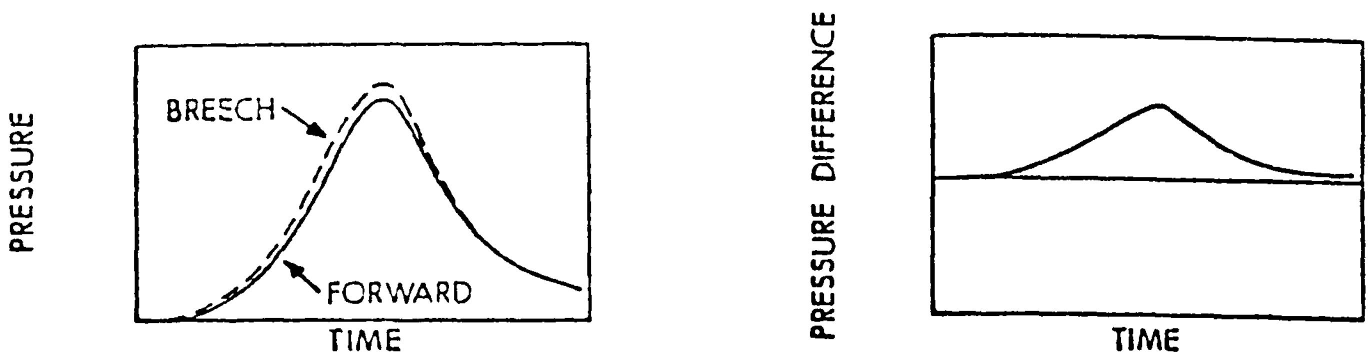


Figure 1. Pressure-Time and Pressure-Difference Profiles - Ideal.

Stick propellant is finding increasing application in high-performance artillery charges. Currently employed in a number of European top-zone propelling charges, stick propellant has been introduced into US artillery as a product improvement to the existing 155-mm, M203, propelling charge as well as into 105-mm and 120-mm tank ammunition systems. Further, its use is all but assured in future advanced artillery systems under consideration in the United States.

The current popularity enjoyed by stick propellant can be attributed to a number of very desirable ballistic advantages associated with its use. The natural flow channels associated with bundles of sticks reduce the resistance offered to the igniter and initial propellant combustion gases in comparison to a granular propellant bed.[7-10] Locally high pressure gradients cannot therefore be supported in a stick propellant charge, and potentially damaging longitudinal pressure waves are all but unseen. In addition, the regular packing of propellant sticks yields higher loading densities than for randomly packed granular propellant. Thus, an equivalent performance could be achieved with a slightly increased mass of a lower-energy, lower-flame-temperature stick propellant

The propellant currently used in the M203A1, Zone 8 charge is triple-base, slotted, single-perforated M31A1E1. A nitrocellulose combustible case which contains a lead foil/wax/TiO2 liner circumferentially placed around its inside diameter is the packaging container for the propellant. Unlike its counterpart, the M203 granular charge, which is packaged in a cloth bag, the nitrocellulose combustible case package is very rigid. Ignition for the new M203A1 is achieved by using a basepad containing a center spot of Class 3, Black Powder, surrounded by a disc of Clean Burning Igniter (CBI), making the system much simpler than the base and centercore ignition required of the older M203, Zone 8 charge. Although the peak pressure for the M203A1 charge is higher than that for the M203 charge, both charges, schematically shown in Figure 2, are velocity-equivalent.

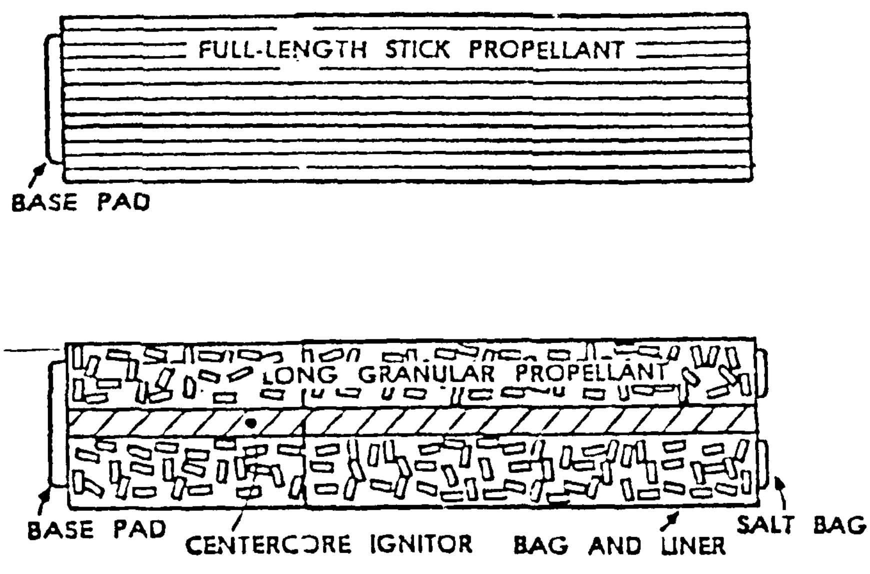


Figure 2. Schematic Configurations of M203 Granular and Stick Charge.

To further enhance the M203A1's capability, the M31A1E1 propellant in the current charge was replaced by a propellant with a high-progressivity/high-density (HPD) geometry. This HPD was achieved both by using a more progressive propellant configuration (19 perforations versus one perforation in the current charge) and by a more densely-packed geometry which gave a higher density-of-loading than the M31A1E1 propellant. By using this HPD concept, the advantages possible over the current M203A1 charge were increased muzzle velocity at current chamber pressures, a simple base-ignition system, and virtually no indication of pressure waves. To ascertain the efficacy of this new charge concept, the relationship between maximum chamber pressure and the proper venting of the multiperforated stick propellant by partial cutting (PC) perpendicular to the axis of the stick must be experimentally determined.

2. TEST SETUP

Gun firings were conducted in a 155-mm howitzer using locally available granular and stick propellants, M549 projectiles and auxiliary components necessary for the fabrication of charges. The weapon, instrumentation, charge design and construction, propellant cutting devices, as well as the technique for propellant cutting are described in the following sections.

A 155-mm, M199 howitzer tube, Serial Number 28501, modified with pressure ports at several axial locations was the test weapon for all the firings. The standard muzzle brake was not used in these tests. For this weapon, the standard, lanyard-operated, spring-driven firing pin was replaced by a gas-activated firing pin. The gas necessary to drive the modified firing pin into the M82 percussion primer was obtained from an M52A3B1 electric detonating cap. The rapid and reproducible functioning of the M52A3B1 enabled instrumentation to be accurately timed by this firing system. An M158 recoil mechanism in conjunction with the upper carriage from a 155-mm, M59 gun was used to mount the APG sleigh which housed the 155-mm, M199 howitzer tube. All tests with this weapon were done at the Sandy Point Firing Facility (Range 18) located at the Ballistic Research Laboratory (BRL).

2.1 Instrumentation.

Instrumentation on all tests consisted of six Kistler 607C3 piezoelectric pressure transducers housed in a howitzer which was capable of mounting gages at nine axial locations. There were two gages in the spindle face at the back of the chamber (P1 and P2), two at the front of the chamber (P5 and P6 at 83.3 cm), one at a midtube location (P9 at 332.5 cm) and one at or near the muzzle (P12 at 576.3 cm). The gage positions are schematically shown in Figure 3. The four gages in the chamber (a redundant, cross-chamber gage at two positions) were sufficient to yield an approximation to the pressure-time profile in the chamber (Figure 4). By differencing either of the spindle gages with the forward chamber gages, the first negative pressure difference, $-\Delta$ Pi, was determined. Projectile displacement was determined by using a 15-GHz doppler radar to measure projectile motion both within and 10 metres beyond the gun muzzle. Projectile velocities were determined from both the doppler output (muzzle velocity) and from three solenoid coils placed 14, 21, and 29 metres, respectively, downrange of the weapon (in-air velocity). By knowing the distance between the coils and the time intervals, two different in-air velocities could be calculated. Ignition delay was defined and recorded as the time from application of the firing voltage to the M52B3A1 electrical primer until the breech pressure reached 7 MPa. Generally, the data were recorded in real time by the Ballistic Data Acquisition System (BALDAS) under the control of a PDP 11/45 minicomputer. If the data were not recorded online because of some unusual ignition delay or computer malfunction, they were later digitized from an analog tape recording made of each test firing.

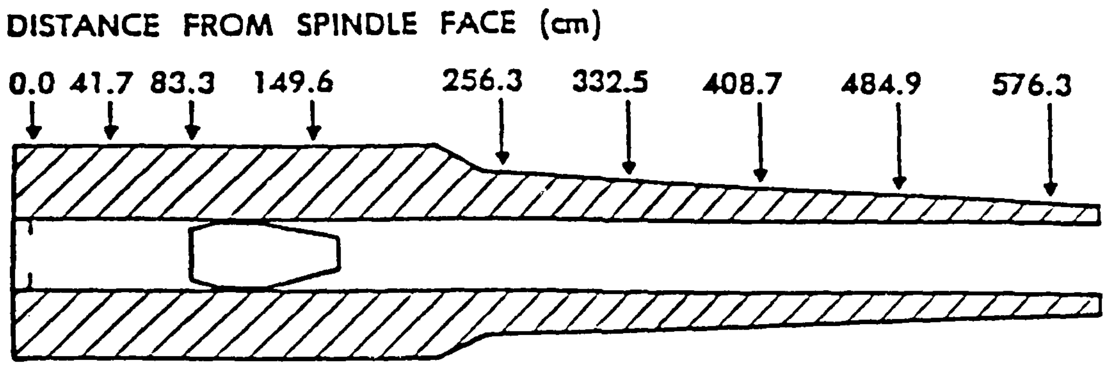


Figure 3. Locations of Pressure Gages in the 155-mm, M199 Cannon.

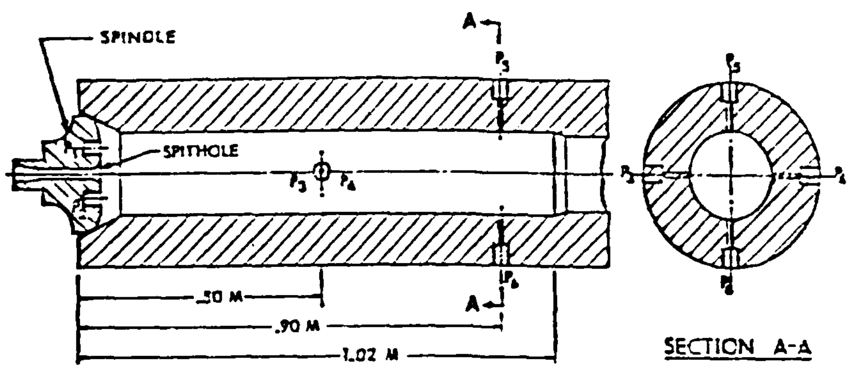


Figure 4. Locations of Pressure Gages in the 155-mm, M199 Cannon Chamber.

2.2 Charge Design and Construction.

Standard 155-mm, M203 Propelling Charges, Lot IND-79K-069960, were obtained for use as the standard baseline round to compare against the locally-fabricated test rounds. This M203 charge is the top zone granular charge for the US Army 155-mm, M198 Towed Howitzer. Depicted in Figure 5, this charge employs M30A1 triple-base propellant, ignited by a basepad and centercore ignition system both containing Class 1 Black Powder. The test charges were fabricated by simply banding together, with binding cord, the necessary number of 19-perforation JA2 propellant sticks to give the charge weight desired. A basepad consisting of 100 grams of Black Powder Class 1, was also attached with tape to one end of the charge. All charge modifications (loading, basepad construction, etc.) were done at the BRL. All charges were conditioned at a temperature of 21° C for at least 24 hours prior to firing. M549 projectiles from Lot IOP-78E001S066, inert-loaded with wax to 43.1 kg, were used for all tests. Projectile weight and rotating band condition (burrs, indentations, etc.) were ascertained prior to loading into the howitzer; projectile seating distance was measured prior to loading the propelling charge.

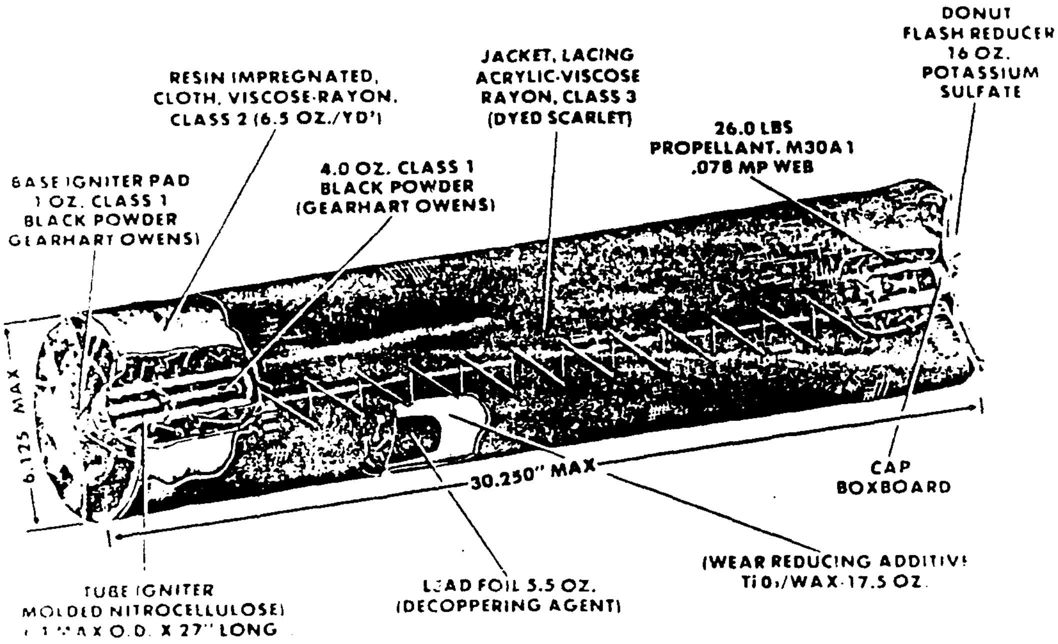


Figure 5. <u>M203</u> <u>Propelling</u> <u>Charge</u>.

2.3 <u>Propellant</u> <u>Cutting</u> <u>Devices</u>.

In order to use long sticks of single perforated propellant, such as is currently used in the M203A1, or multiperforated propellant which is attractive both from its loading density and progressivity, the perforation of the propellant must be vented in some manner so that propellant gases burning inside the perforation can escape to the outside of the grain. The internal pressurization of the long, unvented perforation which poses the potential for mechanical failure of the grains, exposing unprogrammed burning surfaces and leading to overpressurization of the chamber, is of considerable concern. For each grain concept, venting (Figure 6) is done differently. With the single perforated grain, one longitudinal slit, running the length of the grain, is made. For multiperforated propellant, the venting is done by making cuts perpendicular to the propellant axis. The cuts at each axial location must open up all the perforations to be effective; otherwise the propellant will build up internal perforation pressure that will fracture the grain. This would lead to large pressure increases which could rupture a gun tube.

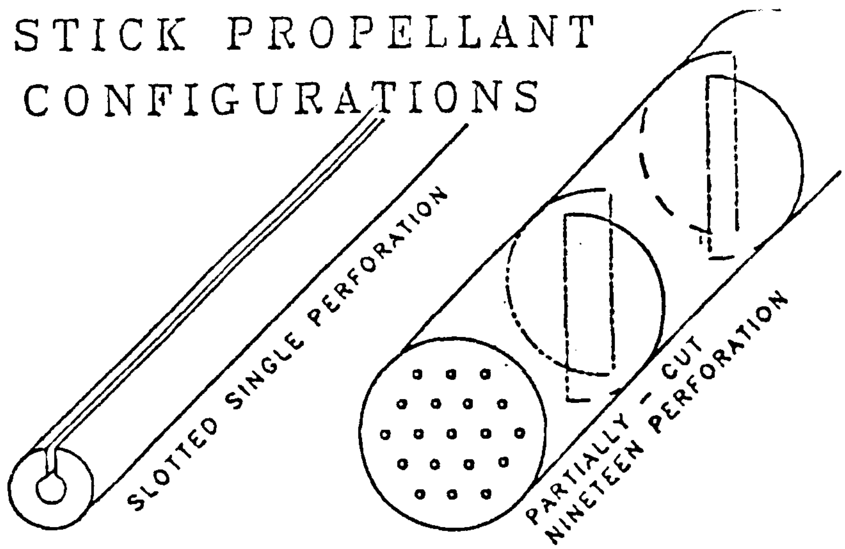


Figure 6. Methods for Venting Single and Multiperforated Stick Propellant.

The method developed at the BRL for venting the propellant consists of the following steps: First, a set of equally-spaced partial cuts at specified intervals perpendicular to the grain axis are made. The cuts must extend to a depth greater than the radius of the grain. After the first set of cuts is made, the propellant grain is rotated 180 degrees, moved axially 3 mm, and a second set of cuts is made. This procedure insures that within 3 mm of each specified interval of the partial cuts, all the perforations of the grain are vented. The cutting technique keeps the grain in its original stick geometry, allows some flexibility in working with the grain during the loading process, and gives a quick, visual quality-control check on the partial cutting operation.

Two cutting devices, one transitional and one permanent, were made to PC propellant for various tests ongoing at the BRL. The transitional device is shown in Figure 7. It consisted of two rectangular blocks of cherry wood modified, as illustrated, to both hold and cut the multiperforated stick propellant. The top unit (cutting block) was modified with narrow 1-mm slits so that razor blades could be inserted into the block, backmounted against the cutting block, and then glued in place. Two cutting blocks, indexed for placement of blades at intervals of 3.8 cm and 7.5 cm, respectively, were fabricated. The base unit (holding block) was modified with a v-shaped trough to hold the stick propellant so that at least half the diameter of the propellant was above the top flat surface of the holding block. Slits, 10 mm wide, were made in the block perpendicular to the trough so that the razor blade cutters would have a recess and not be napped off during the cutting operation. To cut a piece of propellant with this device, the sample was placed with its one end at the index end of the holding block and the block positioned on the support mount of an Arbor press. The cutting block was placed on top of the propellant and positioned so that the steel razor cutters lined up with the slits in the holding block. The cutting block was held in place by the compressing unit of the press. Force was applied until the blades had cut through slightly more than half the diameter of the propellant grain. After the propellant was removed from the cutting block by using two pry bars, the propellant was then turned 180 degrees, moved axially 3 mm and recut to a depth slightly more than half the radius of the grain. This insured that the cuts on this surface were slightly offset from the original cuts and that both sets of cuts had overlapped each other, thus guaranteeing that all the perforations had been cut. After the cutting operation was completed, the stick propellant was still in its original geometry and more importantly, was able to be examined as to the quality control of the cutting operation.

Although the transitional cutting device worked, the method of disengaging the propellant from the cutting block with pry bars was time consuming and the potential for injury from the razor blades was high. Soon into our tests, the BRL permanent device which was in-house designed and fabricated (Figure 8) was ready for our use. The great advantage of this device was that the base structure was attached to the support mount of the Arbor press and was restricted from moving. As it held the propellant,

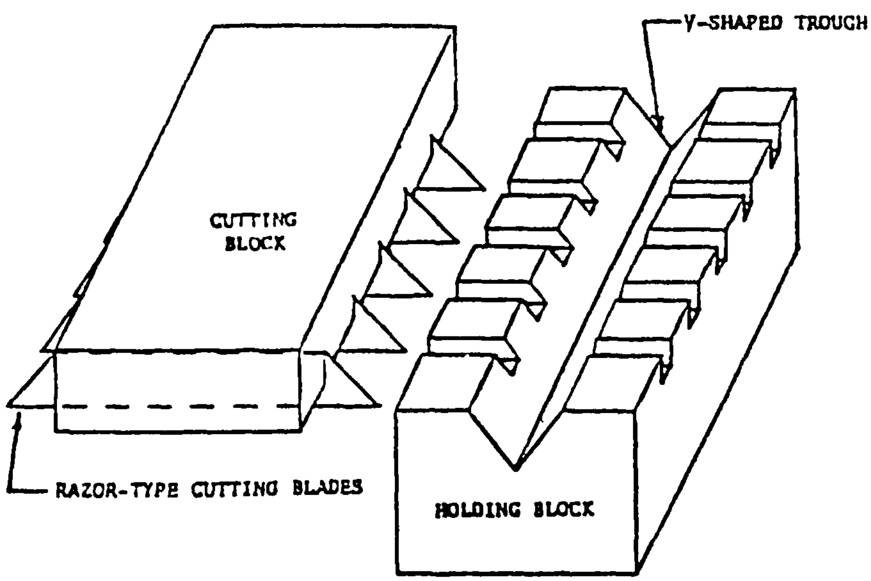


Figure 7. Transitional Fixture for PC Propellant.

it also prevented the propellant from moving during both the downward cutting operation and the upward release of the cutting device from the propellant. The cutting device, in turn, was permanently attached to the ram of a hydraulic press so that as pressure was applied or released, the cutting device moved accordingly.

As in the transitional system, there are two basic parts to this cutting device (Figure 8). The base structure, made of aluminum, consists of a bottom section with a half-cylindrical trough for holding the propellant. Slots (3 mm wide x 50 mm long x 25 mm deep) at 3.8 cm intervals and perpendicular to the axis of the base, are positioned along the length of the base. The top section of the base structure mates with the bottom section. It also has a half-cylindrical trough with slots running completely through from the top to the bottom surface. These slots mate with those in the bottom section. When the top section, which is attached to the bottom section by a pivot joint, is closed and locked to the bottom section, the structure holds the propellant in place. The slots in both sections are so placed that PC can take place on intervals of 3.8 cm.

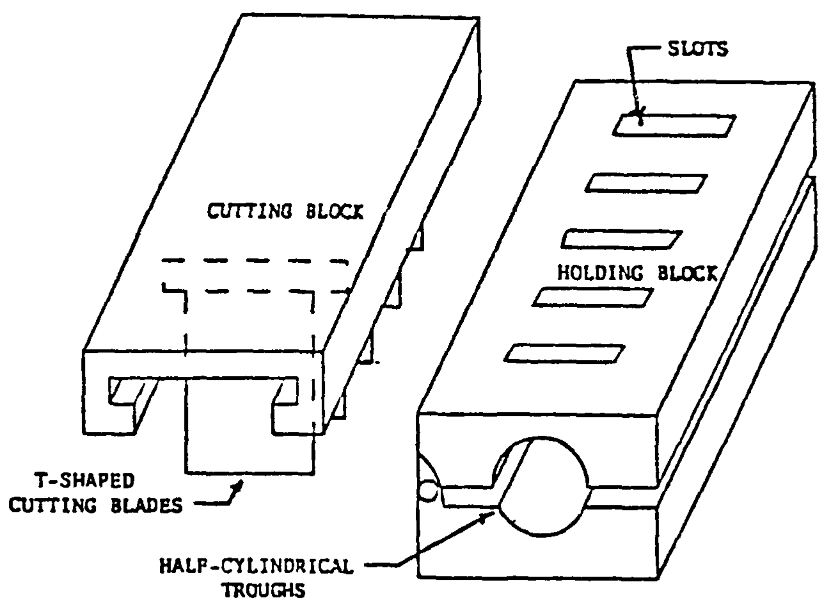


Figure 8. BRL-Designed, Permanent Fixture for PC Propellant.

The cutting section of the permanent device is so designed that special cutting blades fit into a T-shaped groove at intervals specified by spacers so that any combination of 3.8 cm intervals can be obtained simply by changing the spacer arrangement. When the proper spacing is made, the blades are locked in place for the duration of the cutting operation. As before, the propellant has to be rotated 180 degrees to complete the cutting operation. The advantages of this system are that it is designed for easy changing of spacers, for holding the propellant in place during both cutting and release, for movement of the cutting device by hydraulic devices, and for eliminating contact with sharp cutting devices.

3. RESULTS

Propellant lots used for this project are shown in Table 1 and the Propellant Description Sheets are in Appendix A. The 2.39-mm web propellant was used for illustrating the importance of PC in multiperforated stick propellant and its effect on ignition and combustion variability as indicated from pressure and velocity measurements. The 2.54-mm web propellant, being slightly larger and thus closer to that calculated for the optimum web for the 155-mm system, was used to demonstrate the performance increase, as indicated from higher muzzle velocities, obtained using a multiperforated stick propellant in comparison to the standard M203, Zone 8 granular configuration.

Table 1. Multiperforated JA2 Stick Propellant Used in Tests.

Propellant	Lot Number	Web (mm)	Length (mm)	Diameter (mm)	Perf (mm)
JA2	RAD-PE-792-28	2.39	474	18.1	0.766
JA2	RAD-PE-792-26	2.54	476	18.3	0.559

3.1 Firings with RAD-PE-792-28, JA2 Propellant.

The importance of properly venting long sticks of propellant, whether single perforated as in the improved M203 charge or multiperforated as in some of the new charge concepts coming into use, is an ongoing concern that has been heavily investigated[8-10] at the BRL. Related investigations have underscored the importance of the optimized venting of the grain for proper ignition and combustion to proceed in an acceptable and predictable fashion. Both the perforation diameter and the burning rate of the propellant contribute significantly to the level at which pressure builds up in the perforations leading to unprogrammed breakup of the grain. To demonstrate the importance that the venting parameter plays in the proper ignition and subsequent combustion of the propellant grain and its effect on peak pressure, tests were conducted with the smaller of the two webs of JA2 propellant, RAD-PE-792-28.

All firings were done with the propellant and auxiliary components conditioned at 21^{o} C for a minimum of 24 hours. Charges, which were fabricated at the R18 facility, consisted of bundles of stick propellant held together by binding cord. The main ignition system for the propellant was a basepad containing 100 g of Black Powder, Class 1. In order to determine what charge loading was acceptable when using multiperforated, long-stick JA2 and still stay within the pressure limits of the howitzer, charge establishment firings were done first with the unvented propellant - this being the configuration having the greatest potential for fracture. Fracture would cause unprogrammed increases in surface area leading to high chamber pressure. After the initial round was fired at a very low charge loading, successive increases in charge loading determined that 9.75 kg of JA2 was needed to give a breech pressure of 303 MPa, the pressure obtained with a standard, granular M203, Zone 8 charge.

These several preliminary firings are shown in Table 2 and Figure 9. Because of the uncertainty of firing unvented (no PC), long sticks of multiperforated propellant, the test was started at a charge loading of 4.53 kg, giving a very low spindle pressure of 75 MPa. As the density of loading increased, the incremental changes in charge loading produced progressively greater increases in pressure. The pressure change per unit weight of charge went from 27 MPa/kg to 44 MPa/kg to 50 MPa/kg to a substantial 126 MPa/kg when the charge loading reached or surpassed a critical loading density. At this charge loading level, grain breakup leading to unprogrammed burning surface and reduced grain permeability lead to both high - ΔPi and substantial increases in chamber pressure. For the last charge establishment firing, the pressure waves superimposed on the pressure-time trace, as well as the pressure difference-time profiles, indicate a substantial pressure wave level, with a - ΔPi of 55 MPa. Since the intent of the charge establishment was to determine a safe level of charge loading to conduct the test at or near 303 MPa, the pressure level of the M203 charge, no further increases in charge loading were done.

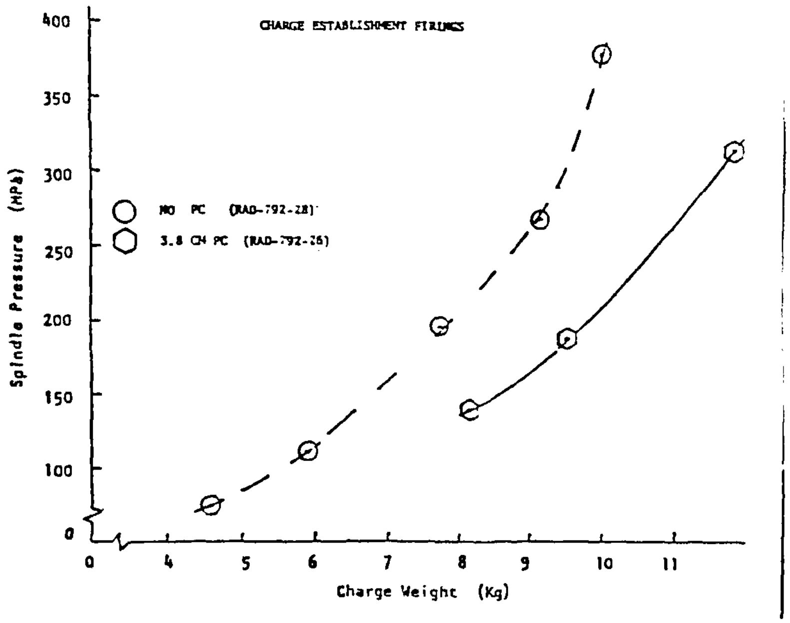


Figure 9. Charge Establishment Firings.

After the charge loading of 9.75 kg was established as described above, two rounds each at 3.8-mm PC, 7.5-mm PC, 15-mm PC, 30-mm PC and no PC were fired. All the firing results are listed in Table 2 and the pressure-time plots are chronicled in Appendix B. The plot in Figure 10 shows the

Table 2. Firing Results for RAD-PE-792-28 Propellant.

PC LENGTH (cm) [Order of Fire]	CHARGE LOADING (kg)	P1 (MPa)	P2 (MPa)	P5 (MPa)	P6 (MPa)	P9 (MPa)	P12 (MPa)	DOPPLER (m/s)	COILS (1-2) (m/s)	COILS (2-3) (m/s)	Ignition Delay (ms)	-ΔPi (Mpa)
Charge establishment firings with no PC												
M203		290	270	283	281	152	-H-	820	818	817	44	4
Checkout		300	300	287	281	156	-H-	820	810	814	54	0
No PC	4.53	75	76	75	74	45	29	454	454	480	33	0
" "	5.90	112	113	109	109	64	42	550	549	546	32	0
" "	7.73	193	197	186	188	98	55	679	---	675	19	5
" "	9.17	265	268	256	261	116	67	763	763	759	18	14
" "	10.04	376	---	345	345	126	78	875	838	831	26	55
Test firings with different PC propellant												
Test M203		270	277	265	265	-H-	101	816	805	803	52	3
Test M203		269	272	260	263	159	103	804	809	802	51	2
End test M203		268	272	-P-	-P-	156	92	806	810	808	50	-P-
No PC												
[1]	9.77	302	308	-H-	291	133	88	796	795	793	28	6
[6]	9.78	302	308	-P-	-P-	123	81	782	786	781	27	-P-
(3.8)												
[2]	9.78	186	190	182	-H-	130	89	722	714	720	18	0
[7]	9.79	169	170	-P-	-P-	117	92	696	696	696	18	-P-
(7.5)												
[3]	9.77	209	213	190	-H-	132	86	735	738	735	14	18
[8]	9.74	215	218	-P-	-P-	133	95	745	747	743	21	-P-
(15)												
[4]	9.79	247	250	243	247	130	82	765	762	765	21	20
[9]	9.79	249	257	-P-	-P-	---	--	---	789	785	20	-P-
(30)												
[5]	9.79	269	274	263	-H-	125	83	781	775	770		
[10]	9.75	300	-H-	-P-	-P-	128	86	797	803	799	17	-P-

-H- Heat from gases got to gage giving anomalous results

-P- Gun gage port plugged with steel dummy gage

--- Data lost

relationship between spindle pressure and the ratio of perforation diameter (Dp) to partial cut length (PCL). As the PCL decreases, an assumed more stable configuration, the ratio increases. Pressure, for a PCL of 3.8 mm was, at 178 MPa, almost a factor of two smaller than for the rounds with no PC. As the PCL increased, the pressure increased, indicating that the burning of the grain, especially in the long inadequately vented perforations, was not burning as geometrically calculated. Although velocities increased with increasing pressure, as would be expected, the unpredictability of the peak pressure for rounds without optimized PCL was shown by considerable round-to-round pressure variation, a condition that would lead to undesirable large velocity variations in a large test series. The effect the PCL has on the peak pressure is shown in Figure 11. Obviously, if we were designing a stick propellant charge with a properly PCL of 3.8 mm, the charge loading would have been much more than used for these tests, since at a PCL of 3.8 mm, the peak pressure was only 178 MPa.

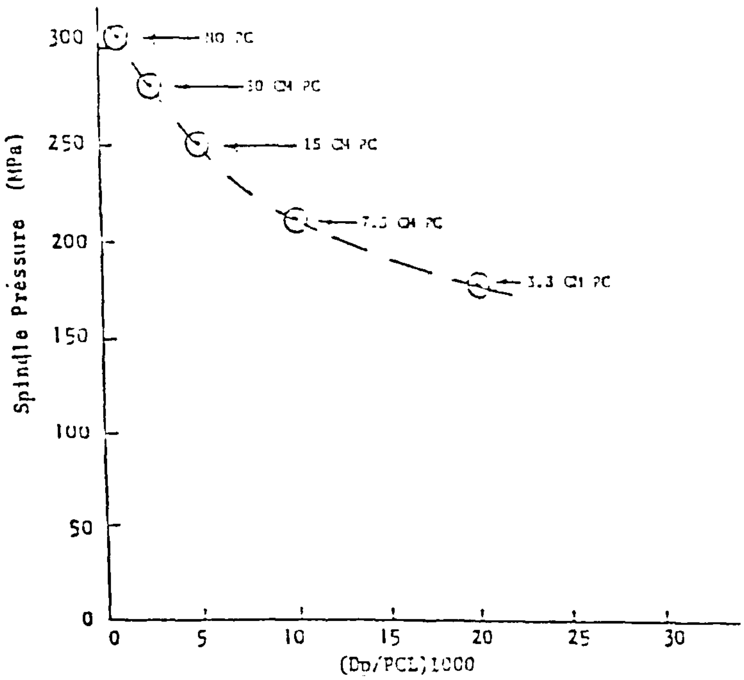


Figure 10. Test Firings for RAD-PE-792-28 Using Different PCL.

3.2 Firings with RAD-PE-792-26, JA2 Propellant.

As in the firings with the smaller web propellant, a short series of firings was necessary with this lot of propellant to establish the charge loading needed to match the pressure of the standard M203, Zone 8 charge. As in the previous tests, all charges were fabricated on-site at R18 and all components were

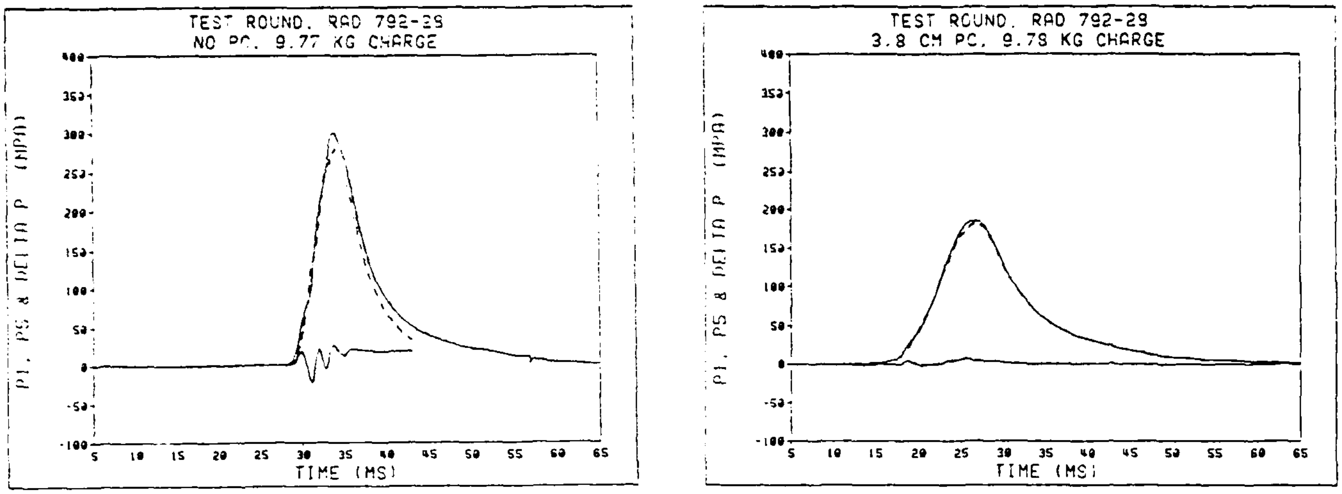


Figure 11. <u>Pressure-Time</u> <u>and</u> <u>Pressure</u> <u>Difference-Time</u> <u>Plots</u> <u>for</u> <u>Unvented</u> <u>and</u> <u>Optimally</u> <u>Vented</u> <u>Multiperforated</u> <u>Stick</u> <u>Propellant</u>.

conditioned for a minimum of 24 hours at 21° C. The previous tests confirmed the importance of the PC spacing for stick propellant. For a PCL of 3.8 mm, the minimum spacing allowed by the BRL fixture, the ratio of PCL to perforation diameter (PCL/Dp) for this lot of propellant was 68. Since this was even larger than the 52 for the previous lot, all the propellant was PC at a PCL of 3.8 mm, the most conservative of the PCL used in the earlier tests. Base ignition was with 100 gm of Black Powder, Class 1, as in the previous tests. Results for the charge establishment firings for RAD-PE-792-26 are shown in Table 3 and Figure 9, respectively.

As noted in Table 3 and graphically illustrated in Figure 9, a charge loading of 11.58 kg was required for obtaining a breech pressure of 303 MPa, the level of the M203, Zone 8 charge. This charge loading was, for a grain with the correct PCL, much larger than with the previous propellant with no PC. The three incremental changes in charge weight from 8.17 to 9.52 to 11.80 kg gave increments of pressure per unit weight of propellant of 37 and 59 MPa/kg, much below the 126 MPa/kg of the previous RAD-PE-792-28 propellant with unoptimized PCL levels. There was no indication, within the range of the data, to suggest that the charge establishment could not have continued to higher charge loading if the intent would have been to reach a much higher chamber pressure.

The remainder of the propellant was used for firing the test series. Chamber, mid-tube and near-muzzle pressures, coil and doppler velocities, ignition delay and $-\Delta Pi$ are shown in Table 3. Even though the web for this propellant was well below the optimum required for a 155-mm system, there was, as expected, an

Table 3. Firing Results for RAD-PE-792-26 Propellant.

PC LENGTH (cm)	CHARGE LOADING (kg)	P1	P2	P5	P6	P9	P12	DOPPLER (m/s)	COILS (1-2)	COILS (2-3)	Ignition Delay (ms)	-ΔPi (MPa)
		(--------MPa----------)							(m/s)			
Charge establishment firings with a PC of 3.8 mm												
M203*		290	270	283	281	152	-H-	820	818	817	44	4
Checkout		300	300	287	281	156	-H-	820	810	814	54	0
3.8	8.17	137	140	137	114	102	69	648	647	644	21	0
3.8	9.52	186	189	181	183	127	79	722	723	719	26	0
3.8	11.80	320	325	311	314	169	86	854	854	849	18	20
Test firing with a PC of 3.8 mm												
Test M203		293	296	282	286	158	88	820	822	819	57	3
Test M203		290	294	280	283	149	87	820	823	820	59	3
3.8	11.58	292	296	282	285	166	89	825	823	820	22	6
3.8	11.58	299	296	282	285	155	89	850	843	-L-	23	18
3.8	11.58	292	296	282	284	160	81	842	848	838	22	16
3.8	11.57	288	292	277	276	169	---	840	843	837	27	10
3.8	11.58	286	290	266	266	166	95	838	843	835	20	11
3.8	11.57	285	289	275	278	166	111	838	840	834	19	17
3.8	11.56	272	275	263	265	171	105	828	830	825	15	11
3.8	11.57	276	28[illegible]	266	268	170	105	831	832	828	16	14
3.8	11.57	278	281	265	269	173	101	831	832	827	14	13

-H- Heat from gases got to gage giving anomalous results

-P- Gun gage port plugged with steel dummy gage

--- Data lost

* Same two M203 checkout rounds as in Table 2 (All charge establishment rounds for both lots fired on the same day)

increase in muzzle velocity over that of the standard M203, Zone 8 granular charge of approximately 2.5 percent. Base ignition similar to that of the M203A1, Zone 8 charge was effective as demonstrated by the ignition delays which were smaller than for the M203 charge. The level of $-\Delta Pi$ was low for all tests.

Since the higher energy of the JA2 and the increased progressivity of the stick configuration both contributed to the increase in velocity, computer runs were done to obtain an approximate estimate of what could be expected with an optimized web of propellant with the results shown in Table 4. Approximately half of the 6.0 percent velocity increase in going from the standard M203 system of 826 m/s to the most optimized JA2 stick configuration of 882 m/s was due to the increase in the propellant energy of JA2 over M30A1 (882 m/s versus 855 m/s). With an optimized web of stick propellant, the optimized velocity calculated over that of the M203 charge could probably be realized.

Table 4. Velocity Comparison for the Standard M203 Granular and Two Optimized Charges of JA2 and M30 Multiperforated Stick Propellant.

PROPELLANT TYPE	CHARGE TYPE	CHARGE (kg)	PRESSURE (MPa)	VELOCITY (m/s)
M203, Zone 8	Experimental	11.80	303	826.2
M30A1 Stick	Calculated	14.79	303	855.4
JA2 Stick	Calculated	14.72	303	881.5

4. CONCLUSIONS

We have demonstrated for high-progressivity/high-density, multiperforated, long grains of stick propellant, the importance of the proper placement of partially cut vents to insure that the initial ignition and subsequent combustion of the grain proceeds as intended both from ballistic code simulations and experimental tests. Without optimum placement of the partial cuts, the internal pressurization of the long, inadequately-vented perforations in the stick propellant leads to grain breakup which causes unpredictable gun pressure levels and higher projectile velocity variations. The relationship between the partial cutting length and the perforation diameter for multiperforated stick propellant, both properly and improperly vented, was demonstrated for two different propellant webs/perforations. Depending on the propellant perforation diameter, the proper partial cutting length could be varied, although for these tests, the perforation diameters did not vary enough to justify larger partial cutting lengths.

Improved ballistic performance was obtained by using a multiperforated stick propellant in place of the granular in the M203 charge and the single perforated stick in the M203A1 charge. By using an optimized web of propellant, it might be possible to achieve a six percent increase in velocity as predicted from ballistic calculations.

A technique and equipment for PC multiperforated grains of stick propellant was developed. The equipment design made for efficient, safe and reliable partial cutting of the stick propellant. Without this physical modification, the use of long, multiperforated stick propellant in gun systems would not be feasible.

5. ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Sandy Point Firing Facility personnel (Messrs. J. Bowen, J. Hewitt, J. Stabile, J. Tuerk, R. May, D. Meier and S. Little) who helped cut the propellant, fabricate and fire the charges and reduce the data. A special thanks to Richard Mudd, TBD, and Irvin Stobie, IBD, for their excellent review of and their suggestions for changes to the report.

INTENTIONALLY LEFT BLANK.

6. REFERENCES

1. I. W. May, "The Role of Ignition and Combustion in Gun Propulsion: A Survey of Developmental Efforts," Proceedings of 13th JANNAF Combustion Meeting, CPIA Pub. 281, Vol. I, pp 315 - 339 September 1976.

2. T. C. Minor, "Characterization of Ignition Systems for Bagged Artillery Charges," ARBRL-TR-02377, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, October 1981.

3. A. W. Horst, T. C. Smith, and S. E. Mitchell, "Experimental Evaluation of Three Concepts for Reducing Pressure Wave Phenomena in Navy 5-inch, 54-Caliber Guns: Summary of Firing Data," MR-76-25, Naval Ordnance Station, Indian Head, MD, August 1976.

4. A. W. Horst, I. W. May, and E. V. Clarke, Jr., "The Missing Link Between Pressure Waves and Breechblows," ARRADCOM-MR-028849, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, July 1978.

5. I. W. May and A. W. Horst, "Charge Design Considerations and Their Effect on Pressure Waves in Guns," ARRADCOM-TR-02277, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, December 1980.

6. P. G. Baer, "Practical Interior Ballistic Analysis of Guns," Interior Ballistics of Guns, Ed. M. Summerfield and H. Krier, Progress in Astronautics and Aeronautics, Vol. 66, pp 37 - 66, 1979.

7. T. C. Minor and A. W. Horst, "Ignition Phenomena in Developmental, Stick-Propellant, Combustible-Cased, 155-mm M203E2 Propelling Charges," ARBRL-TR-02568, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, July 1984.

8. T. C. Minor and A. W. Horst, "Theoretical and Experimental Investigation of Flamespreading Processes in Combustible-Cased, Stick Propellant Charges," Proceedings of the 21st JANNAF Combustion Meeting, CPIA Pub. 412, Vol. II, pp 237 - 251, October 1984.

9. F. W. Robbins and A. W. Horst, "Continued Study of Stick Propellant Combustion Processes," ARBRL-MR-03296, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, July 1983.

10. F. W. Robbins and A. W. Horst, "Detailed Characterization of the Interior Ballistics of Slotted Stick Propellant," BRL-TR-2591, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, September 1984.

INTENTIONALLY LEFT BLANK.

APPENDIX A

Propellant Description Sheets

INTENTIONALLY LEFT BLANK.

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL EXEMPT-PARA 7-2a AR 335-15

COMPOSITION JA-2	LOT NUMBER RAD-PE-792-26
SPECIFICATION COR letter SMCRA-EN dated 3/27/86 *	PACKED AMOUNT 480 Pounds
MFG AT RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	CONTRACT NUMBER DAAA09-86-Z-0003

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
B95063, 95067	MAX ____ %	____ MIN	____ MIN
	MIN ____ %	____ MIN	____ MIN
	AVG 13.11 %	45+ MIN	30+ MIN
			EXPLOSION ____ HR

MANUFACTURE OF SOLVENTLESS PROPELLANT

PERCENTAGE REMIX TO WHOLE ____

TEMPERATURES * FROM	TO	PROCESS— DRYING	TIME DAYS	HOURS
		3-day aging before and after blending at ambient		
Ambient	110°F	Increase at 5°F per hour		
	110°F	Anneal for 6 hours		6
100°F	Ambient	Cool down for processing		

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS: TESTS	FORMULA	ACTUAL
NITROCELLULOSE	59.50	±2.00	58.53	HEAT	cc40'	cc 60'
NITROGLYCERIN	14.90	±1.00	15.66	NO FUMES	NF 1 hr	NF 1 hr
DIETHYLENE GLYCOL DINITRATE	24.80	±1.50	24.96	FORM OF PROPELLANT		
AKARDIT II	0.70	±0.2	0.75	*TALIANI	≤1.0 Hg/mm	
MAGNESIUM OXIDE	0.05	MAX.	0.05		slope at 100mm	**
GRAPHITE	0.05	MAX.	0.05	HOE	1120.0cal	1117.7
TOTAL	100	100	100.00	ABS DENSITY (g/cc)	1.569 min.	1.59
				COMPRESSIBILITY		
Moisture	0.5	+0.3	0.18			

CLOSED BOMB

	LOT NUMBER	TEMP °F	Relative Quickness	RELATIVE FORCE
TEST	RAD PE-792-26	90	82.91	97.06
		145	94.99	98.91
		-40	72.03	95.51
STANDARD	472-138		100.00	100.00%

PROPELLANT DIMENSIONS (inches)

PARAMETER	SPECIFICATION	DIE	FINISHED	STD. DEV. in % of Mean Dimensions SPEC.	ACTUAL
LENGTH (L)	18.75		18.78		
DIAMETER (D)	0.712	0.734	0.708		
PERF. DIA. (d)	0.022	0.020	0.028		
Web (av)	0.100		0.078		
Inner	0.100	0.114	0.092		
Middle	0.100	0.120	0.093		
Outer	0.100	0.082	0.108		
L/D	26.33		26.53		
D/d	32.36		28.32		

REMARKS

Fired in a nominal 700 cc closed bomb at a 0.15 g/cc loading density.

DATES

PACKED	7/20/86
SAMPLED	7/11/86
TEST FINISHED	8/4/86
OFFERED	
DESCRIPTION SHEETS FORWARDED	14 Oct 86

TYPE OF PACKING CONTAINER Wooden Boxes 652D: 8@ 60 lbs Net

REMARKS * Produced to DOD-P-64035(AR)
** Propellant did not reach 100mm of Hg
HOE formula calculations based on "percent measured" results.

This lot meets specification requirements.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE D. R. Brant

SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE Ronald L. Cromer

21

ARRCOM FORM 214R 10 AUG 77

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL
EXEMPT-PARA 7-2a
AR 335-15

COMPOSITION JA-2	LOT NUMBER PE RAD-~~[illegible]~~-792-28
SPECIFICATION COR Letter SMCRA-EN dated 6/12/86 *	PACKED AMOUNT 535 lbs.
FG AT RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	CONTRACT NUMBER DAAA09-86-Z-0003

NITROCELLULOSE

ACCEPTED BLEND NUMBERS	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
B 95063, 95067	MAX ____ %	____ MIN	____ MIN
	MIN ____ %	____ MIN	____ MIN
	AVG 13.14 %	45+ MIN	30+ MIN
			EXPLOSION ____ HR

MANUFACTURE OF SOLVENTLESS PROPELLANT

PERCENTAGE REMIX TO WHOLE

TEMPERATURES ° FROM	TEMPERATURES ° TO	PROCESS— DRYING	TIME DAYS	TIME HOURS
		3 Day aging before and after blending of ambient		
Ambient	110°F	Increase at 5°F per hour		
	110°F	Anneal for 6 hours		6
100°F	Ambient	Cool down for processing		

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	STABILITY AND PHYSICAL TESTS: TESTS	FORMULA	ACTUAL
NITROCELLULOSE	59.50	±2.00	58.93	HEAT	cc 40'	60'±
NITROGLYCERIN	14.90	±1.00	15.52	NO FUMES	NF 1 Hr	NF 1 Hr
DIETHYLENE GLYCOL DINITRATE	24.80	±1.50	24.73	FORM OF PROPELLANT	Cyl	Cyl
AKARDIT II	0.70	±0.2	0.73	TALIANI	≤1.0 Hg mm	0.283
MAGNESIUM OXIDE	0.05	MAX.	0.04		(slope at 100mm)	
GRAPHITE	0.05	MAX.	0.05	HOE	1120.0cal	1117.0
MOISTURE	0.5	Max.	0.18			
TOTAL	100	100	100.00	ABS DENSITY (gm/cc)	1.565 min.	1.605

CLOSED BOMB

	LOT NUMBER	TEMP °F	Relative Quickness	Relative Force
TEST	RAD PE-792-28	+90	85.49	96.90
		-40	72.47	94.50
		+145	95.17	97.44
STANDARD	+72-138	+90	100.00	100.00%

REMARKS

Fired in a nominal 700cc size closed bomb at a 0.15 g/cc loading density.

PROPELLANT DIMENSIONS (inches)

PARAMETER	SPECIFICATION	DIE	FINISHED	STD Dev % of Mean Dimensions SPEC	ACTUAL
LENGTH (L)	18.75		18.66		
DIAMETER (D)	0.712	0.734	0.711		
PERF. DIA. (d)	0.028	0.026	0.030		
Web (Avg)	0.095		0.094		
Inner	0.095		0.092		
Middle	0.095		0.097		
Outer	0.095		0.092		
L:D	26.33		26.25		
D:d	25.43		23.70		

DATES

PACKED	11/7/86
SAMPLED	11/6/86
TEST FINISHED	
OFFERED	
DESCRIPTION SHEETS FORWARDED	

TYPE OF PACKING CONTAINER Wooden Boxes 652D: 8 @ 60 lbs and 1 @ 35 lbs

REMARKS * Produced to DOD-P-64035
HOE formula calculations based on "percent measured" results.
This was a two part production run.

This lot meets specification requirer 22

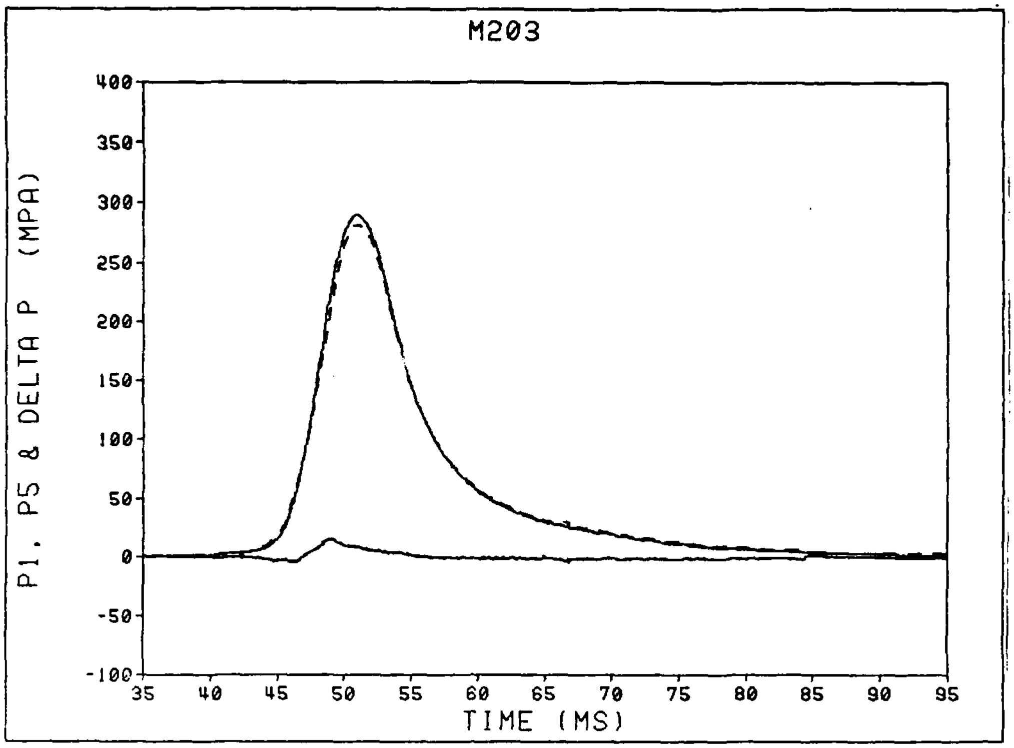
SIGNATURE OF CONTRACTOR'S REPRESENTATIVE	SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE
D. R. Brant D. R. Brant	

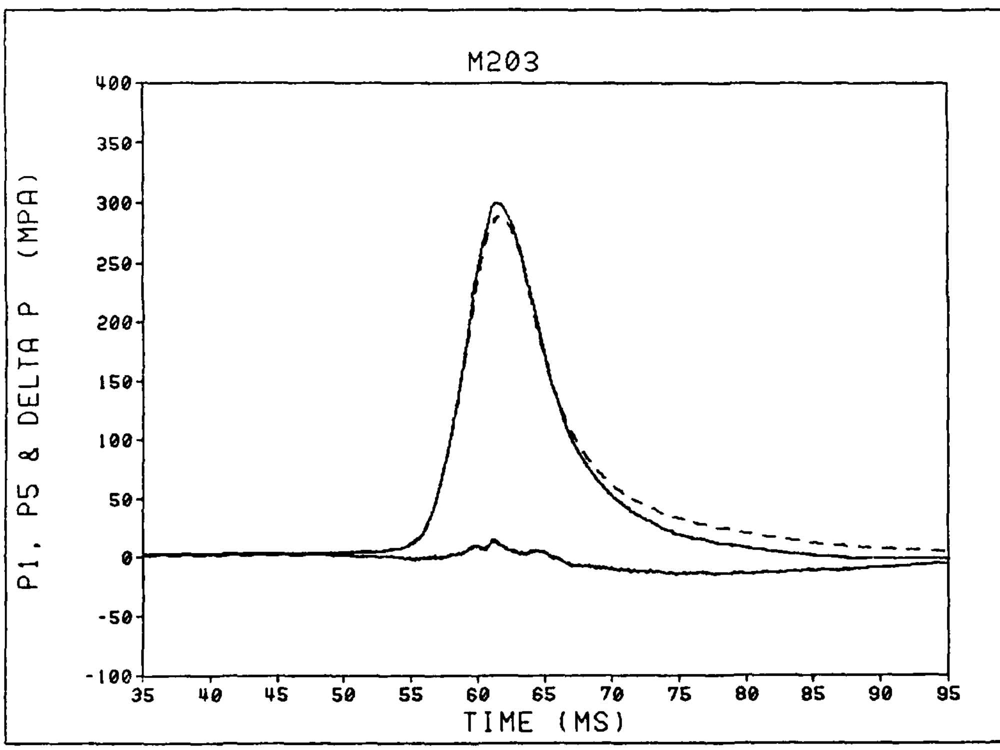
ARRCOM FORM 2148 10 AUG 77

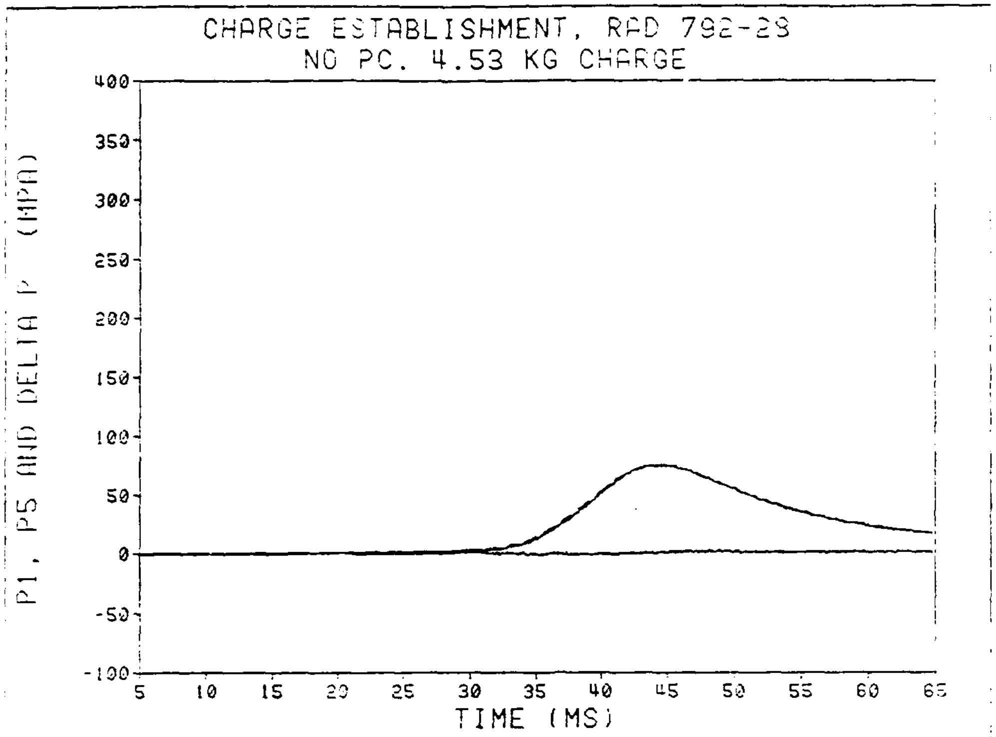
APPENDIX B

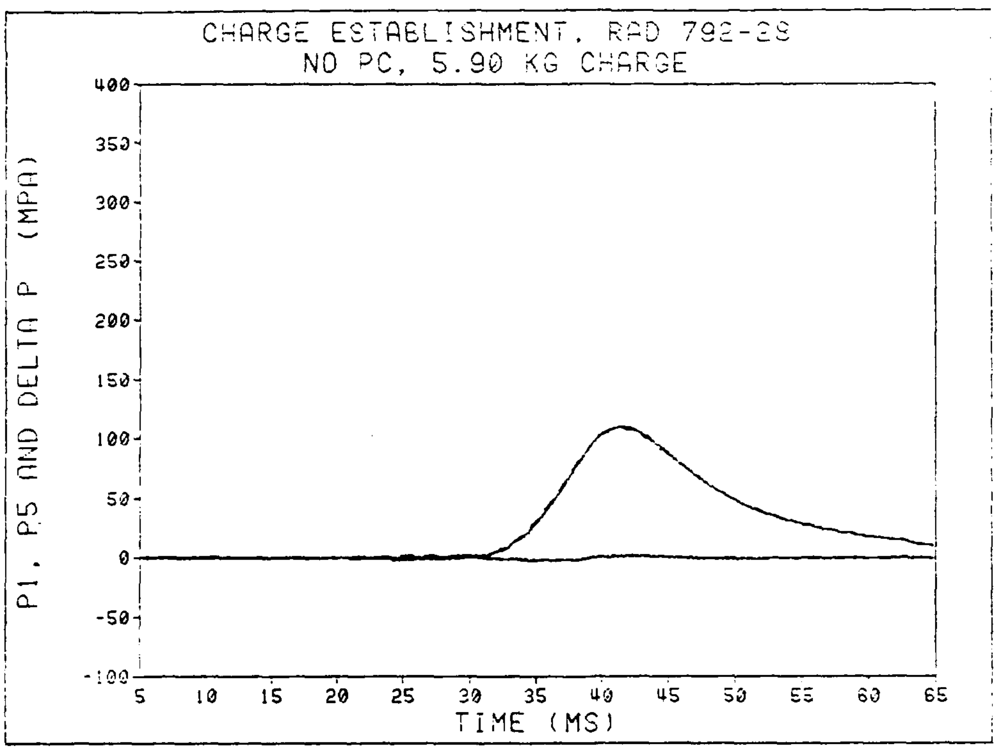
Plots of Spindle Pressure (Solid Line), Forward Chamber Pressure (Dashed Line), and Forward Chamber Pressure (Solid Line) as Sequentially Listed In Tables 2 and 3

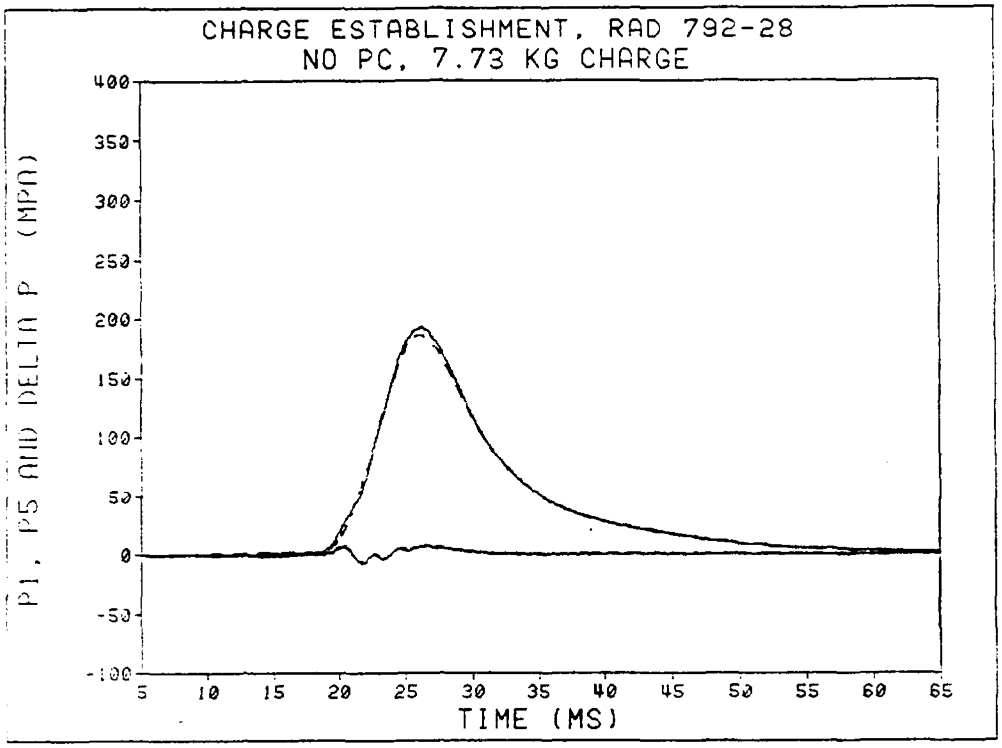
INTENTIONALLY LEFT BLANK.

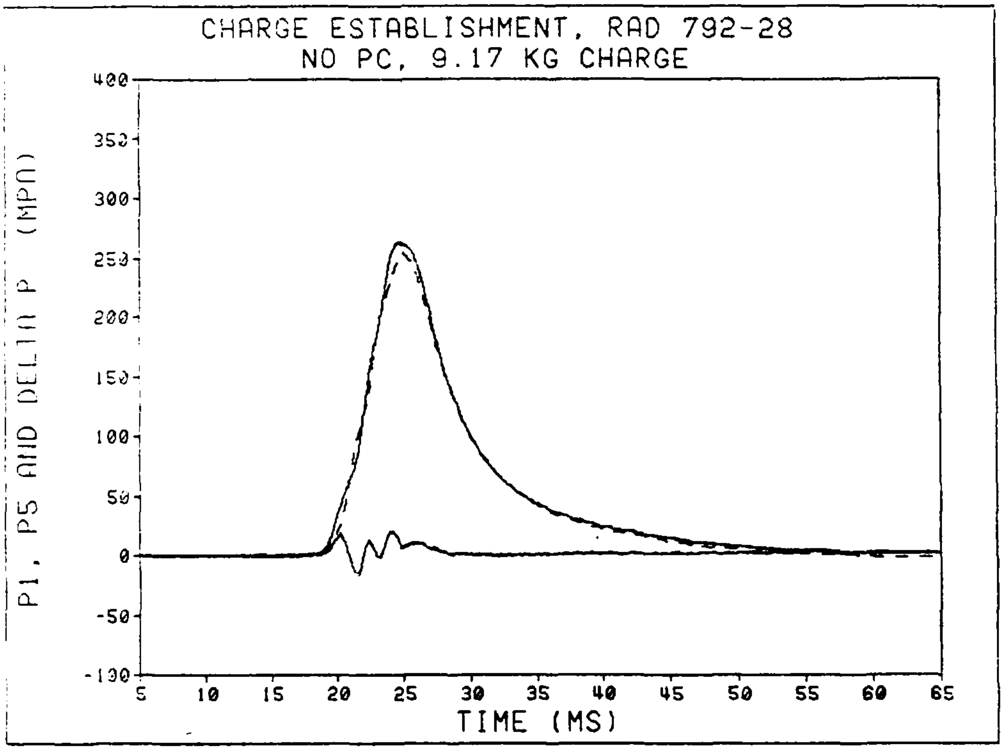

M203
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
35
40
45
50
55
60
65
70
75
80
85
90
95
TIME (MS)

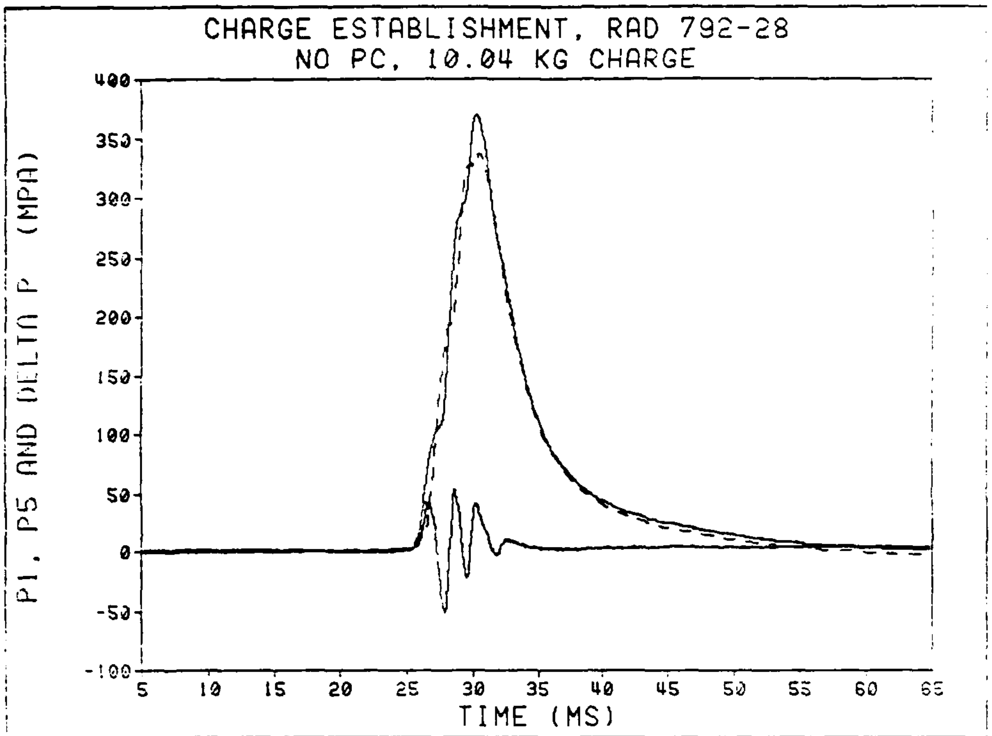

M203
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
35
40
45
50
55
60
65
70
75
80
85
90
95
TIME (MS)

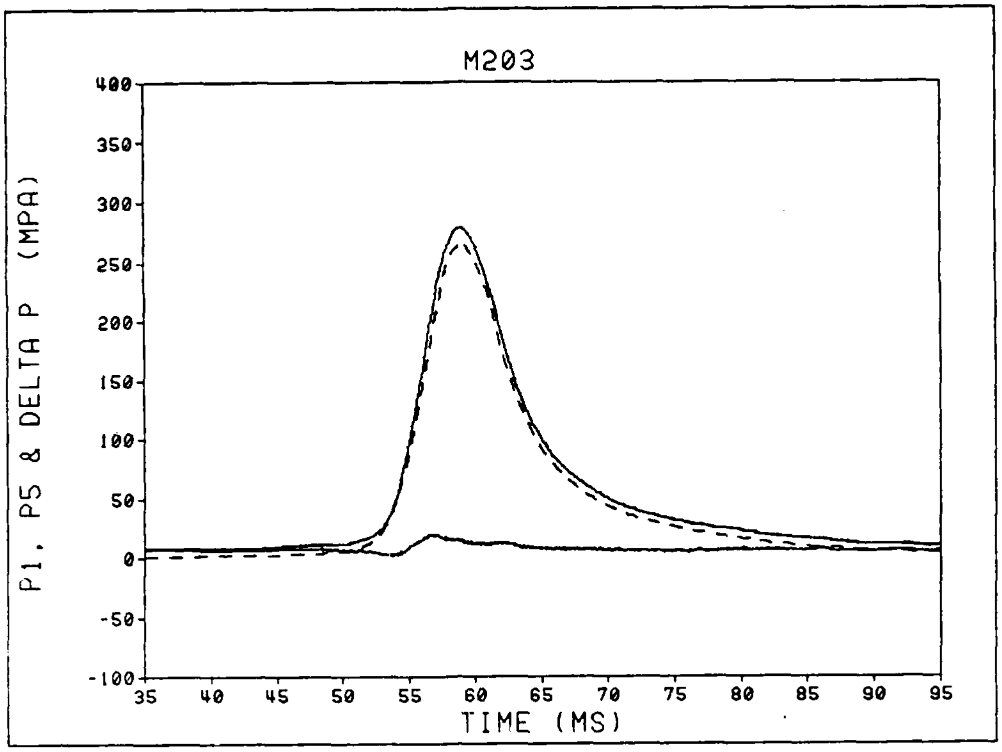

CHARGE ESTABLISHMENT, RAD 792-28
NO PC. 4.53 KG CHARGE
P1, P5 AND DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

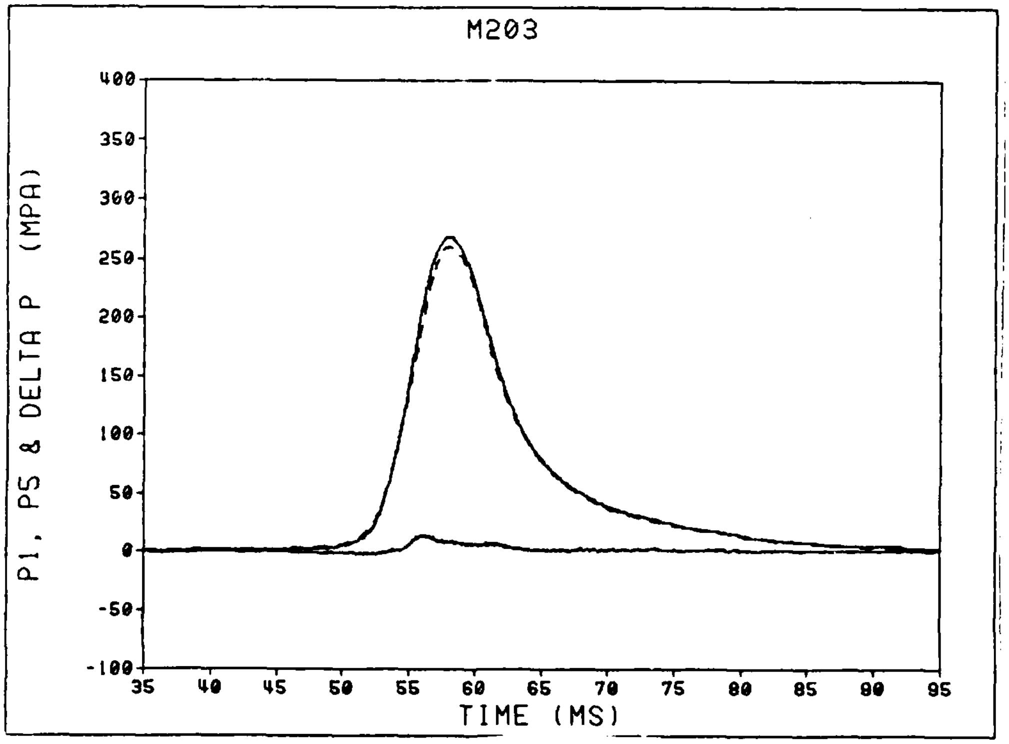

CHARGE ESTABLISHMENT, RAD 792-28
NO PC, 5.90 KG CHARGE
P1, P5 AND DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

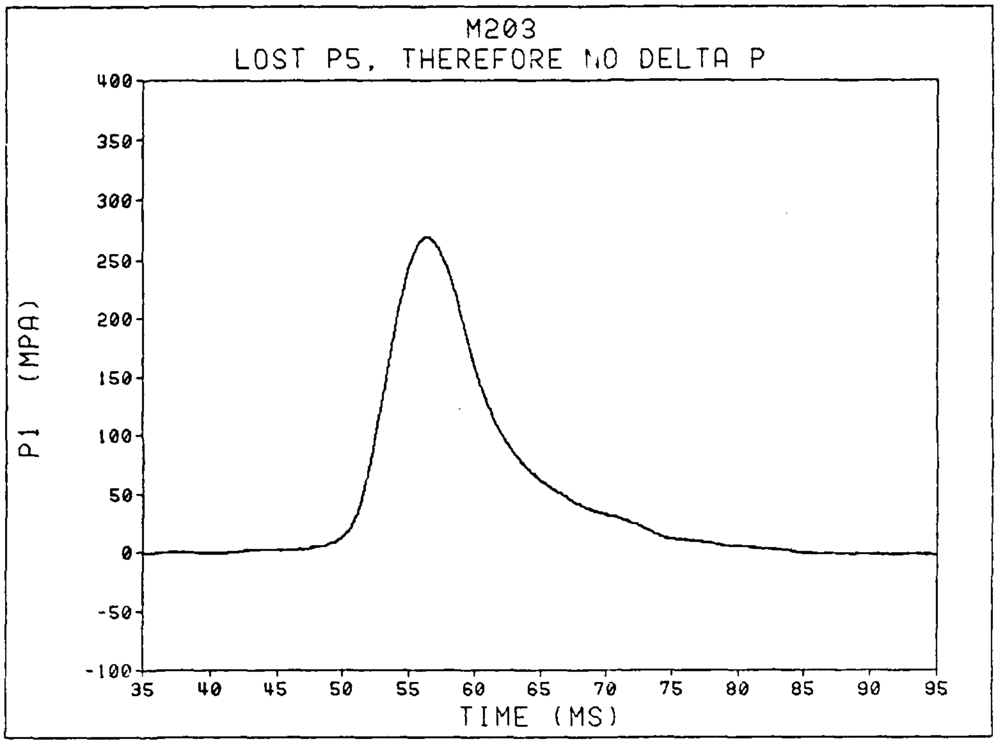

CHARGE ESTABLISHMENT, RAD 792-28
NO PC, 7.73 KG CHARGE
P1, P5 AND DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

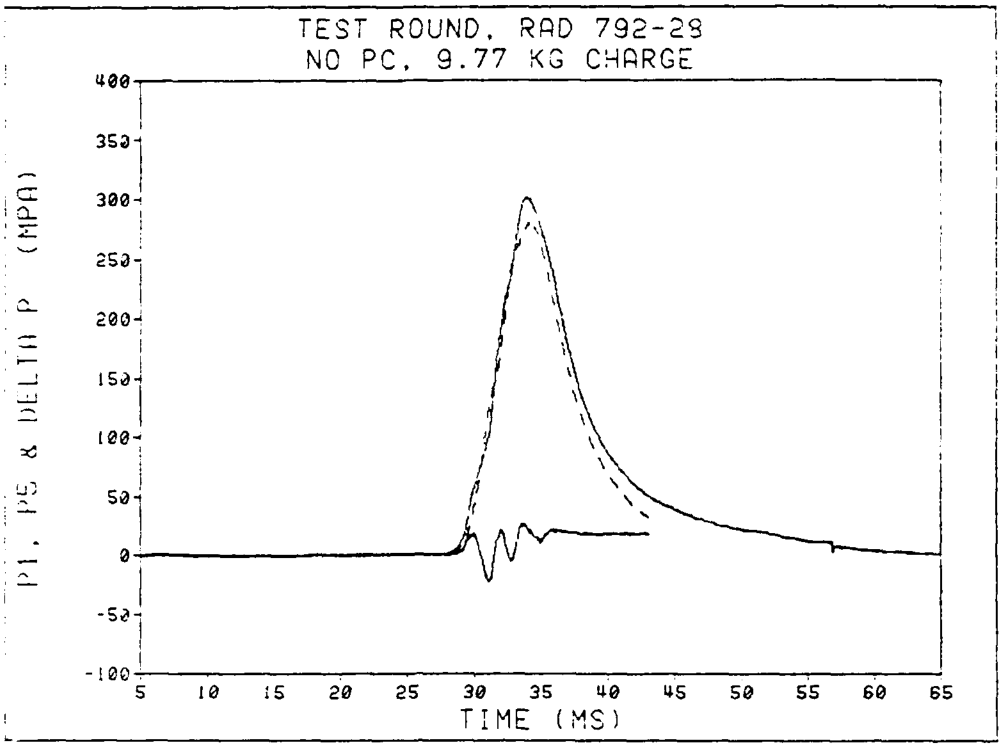

CHARGE ESTABLISHMENT, RAD 792-28
NO PC, 9.17 KG CHARGE
P1, P5 AND DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65


CHARGE ESTABLISHMENT, RAD 792-28
NO PC, 10.04 KG CHARGE
P1, P5 AND DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65
TIME (MS)

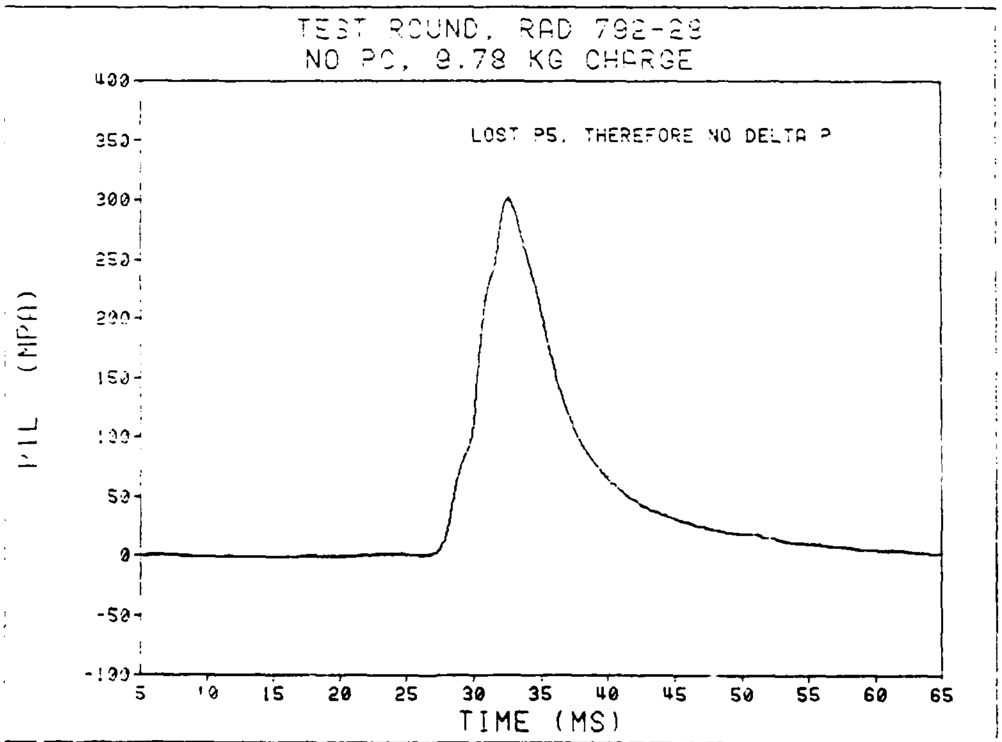

M203
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
35
40
45
50
55
60
65
70
75
80
85
90
95
TIME (MS)


M203
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
35
40
45
50
55
60
65
70
75
80
85
90
95
TIME (MS)

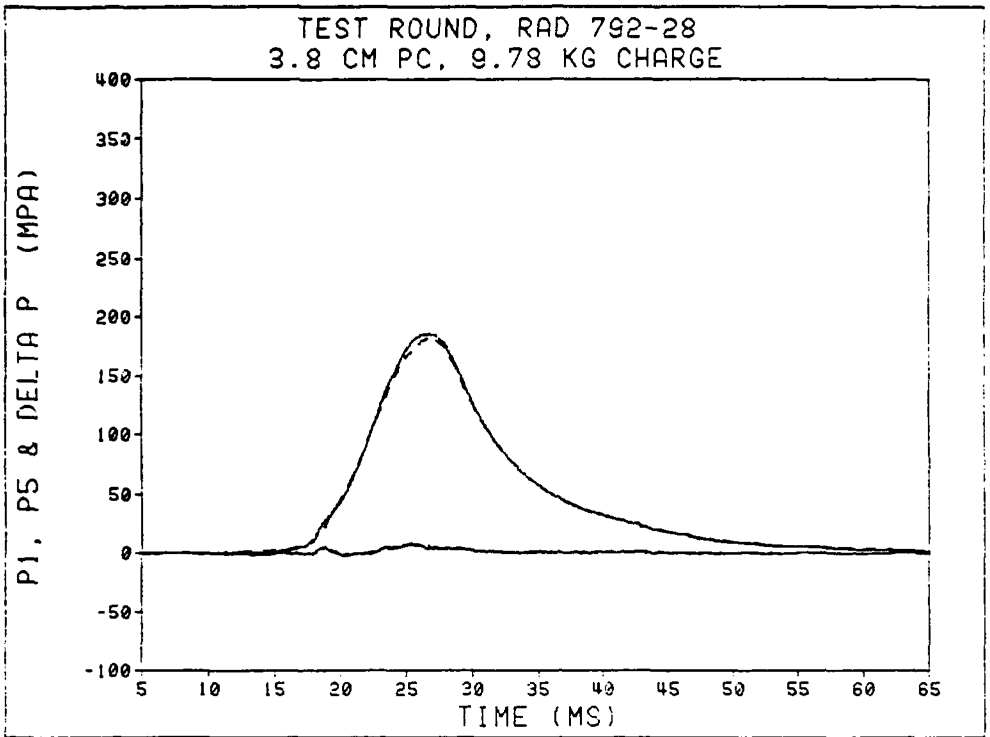

M203
LOST P5, THEREFORE NO DELTA P
P1 (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
35
40
45
50
55
60
65
70
75
80
85
90
95
TIME (MS)

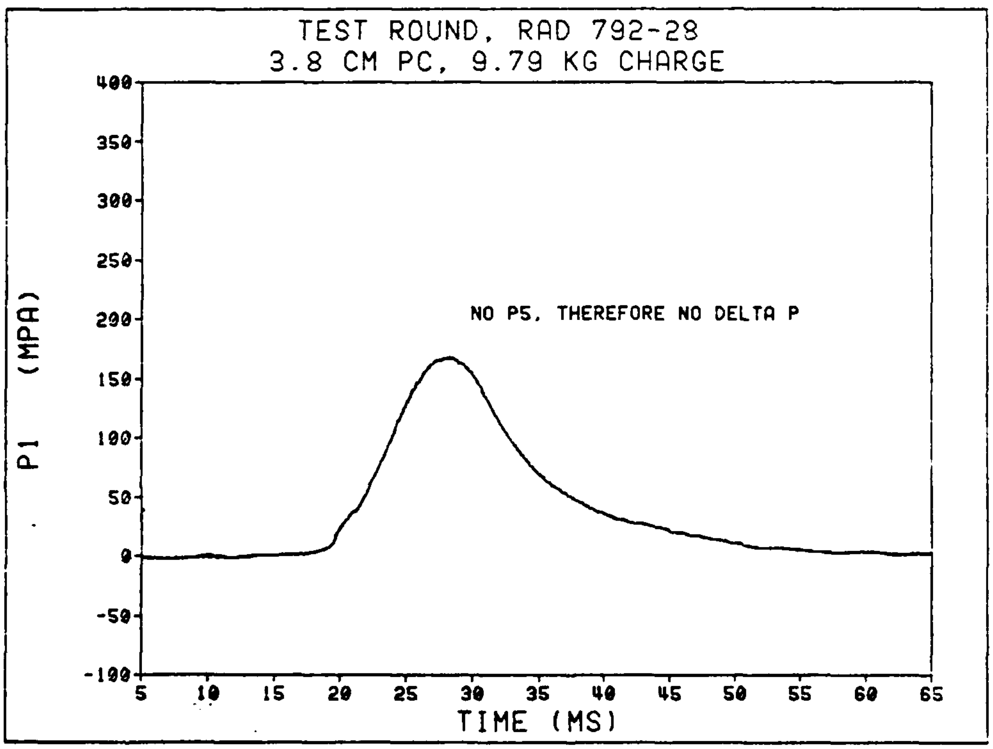


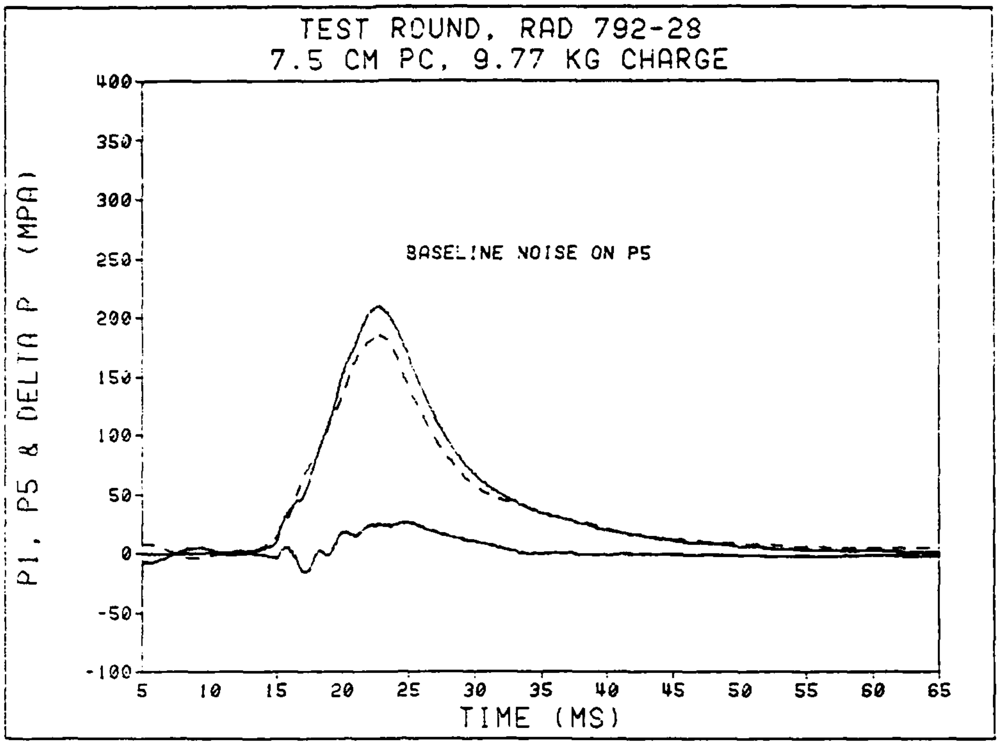
TEST ROUND, RAD 792-28
NO PC, 9.77 KG CHARGE
P1, P5 & DELTA P (MPA)
TIME (MS)



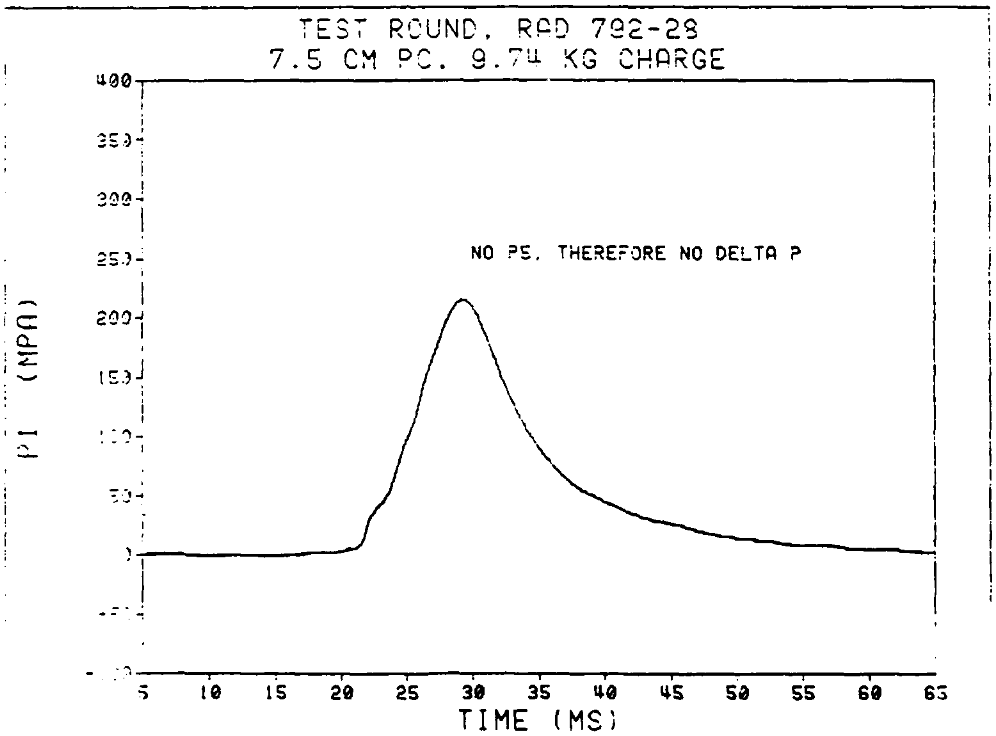
TEST ROUND, RAD 792-28
NO PC, 9.78 KG CHARGE
LOST P5, THEREFORE NO DELTA P
P1L (MPA)
TIME (MS)


TEST ROUND, RAD 792-28
3.8 CM PC, 9.78 KG CHARGE
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65
TIME (MS)

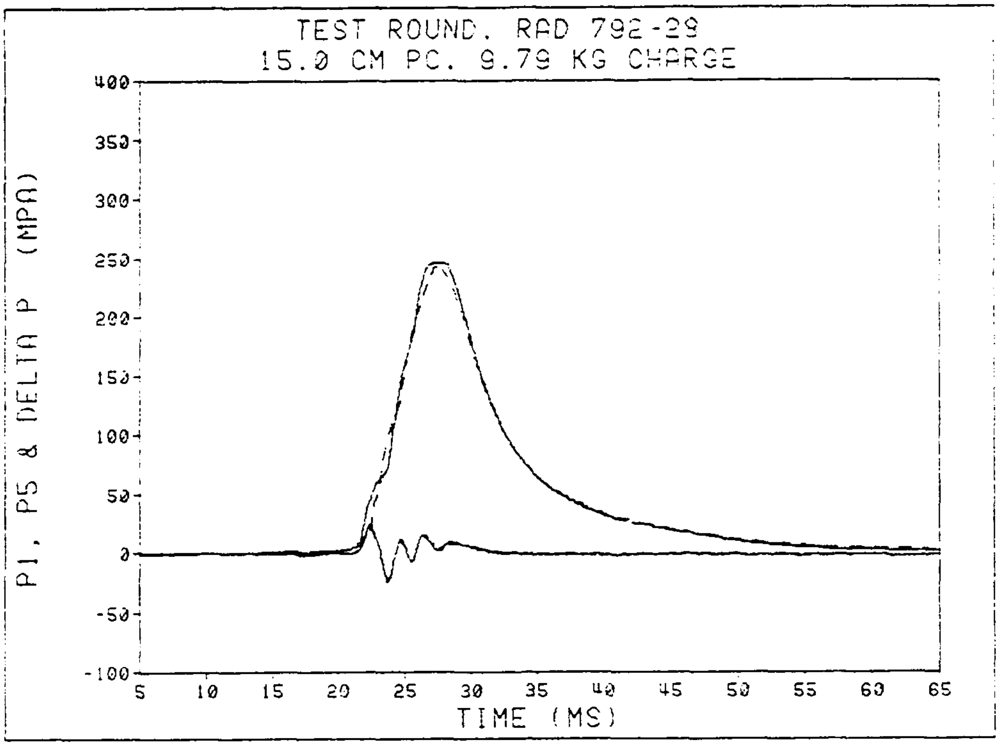

TEST ROUND, RAD 792-28
3.8 CM PC, 9.79 KG CHARGE
P1 (MPA)
NO P5, THEREFORE NO DELTA P
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65
TIME (MS)

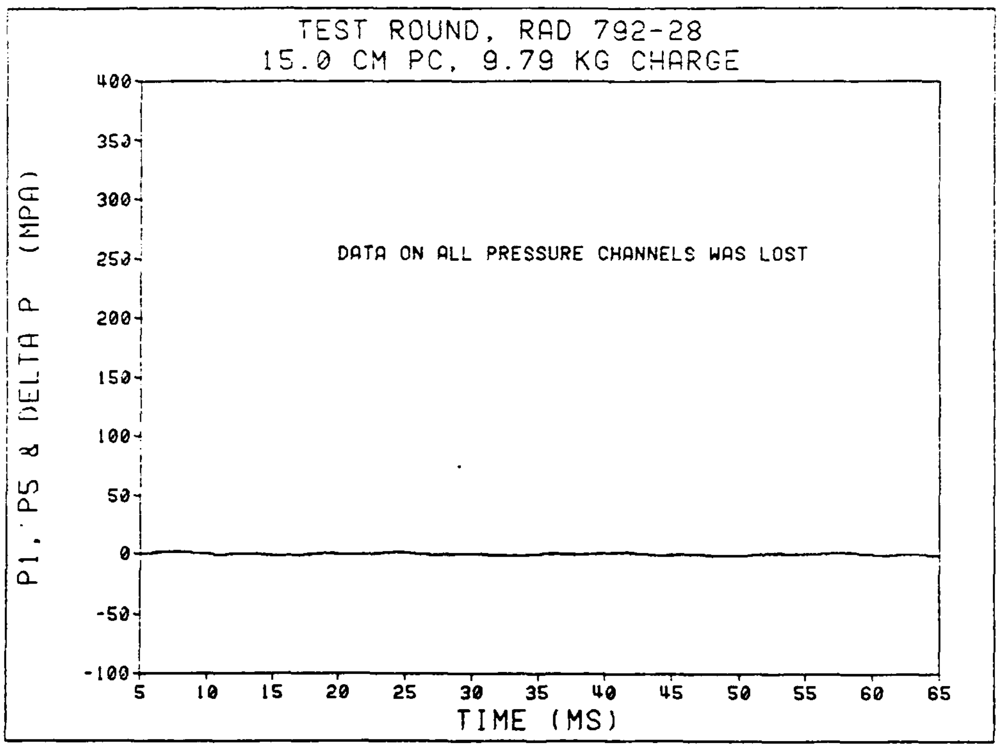


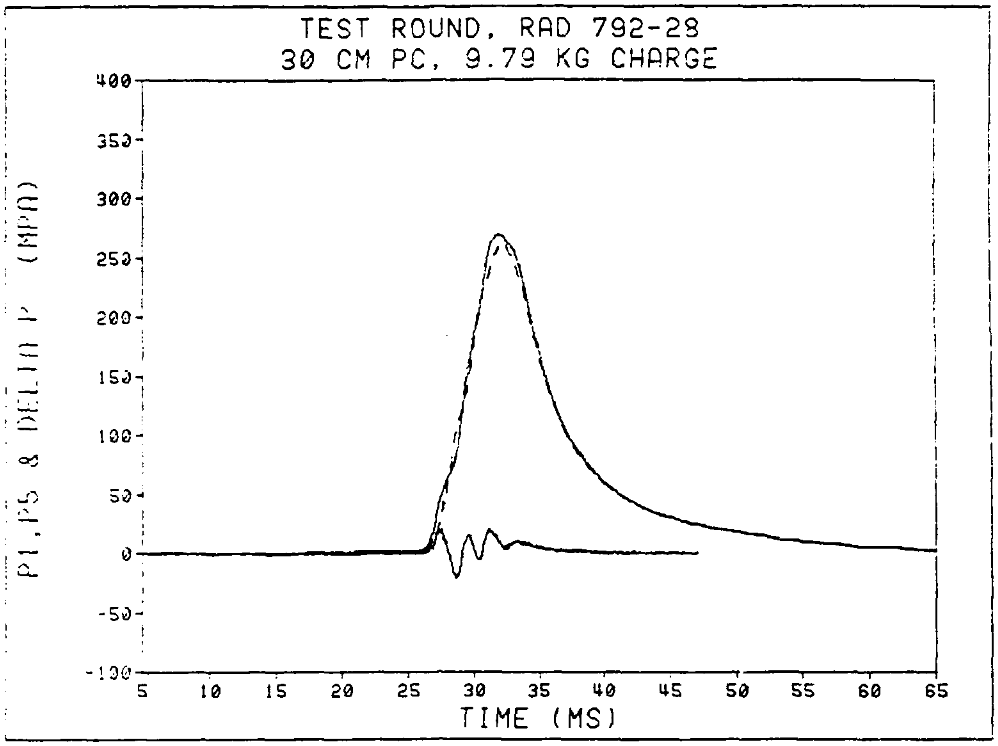
TEST ROUND, RAD 792-28
7.5 CM PC, 9.77 KG CHARGE
BASELINE NOISE ON P5
P1, P5 & DELTA P (MPA)
TIME (MS)

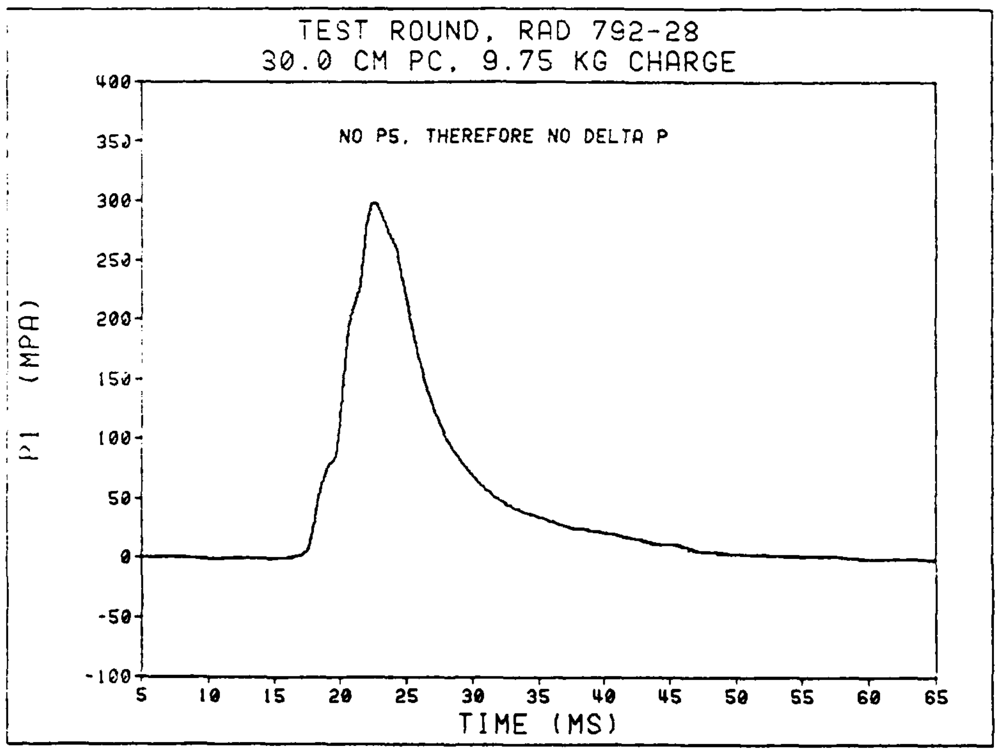


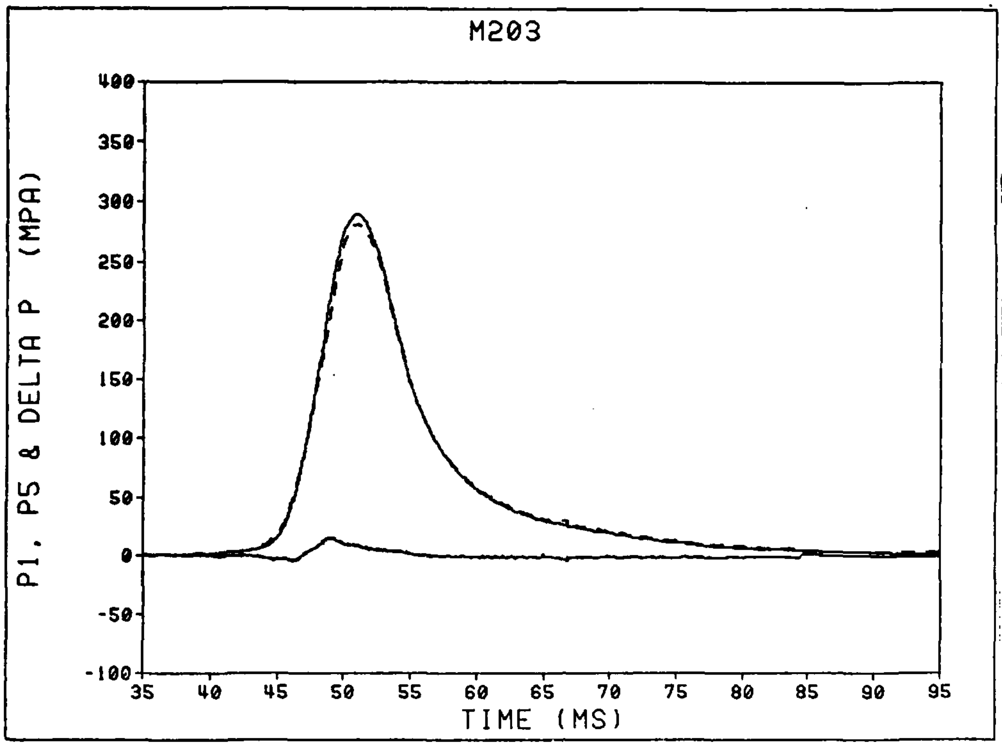
TEST ROUND, RAD 792-28
7.5 CM PC, 9.74 KG CHARGE
NO P5, THEREFORE NO DELTA P
P1 (MPA)
TIME (MS)


TEST ROUND, RAD 792-29
15.0 CM PC, 9.79 KG CHARGE
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65
TIME (MS)

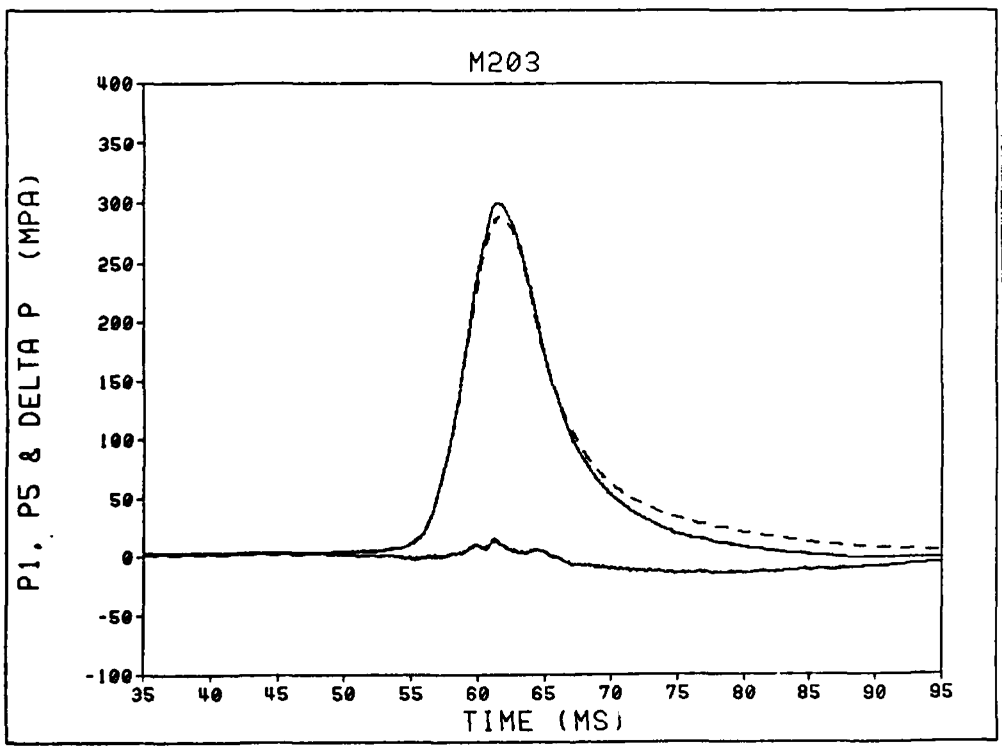

TEST ROUND, RAD 792-28
15.0 CM PC, 9.79 KG CHARGE
P1, P5 & DELTA P (MPA)
DATA ON ALL PRESSURE CHANNELS WAS LOST
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65
TIME (MS)


TEST ROUND, RAD 792-28
30 CM PC, 9.79 KG CHARGE
P1, PS & DELTA P (MPA)
TIME (MS)

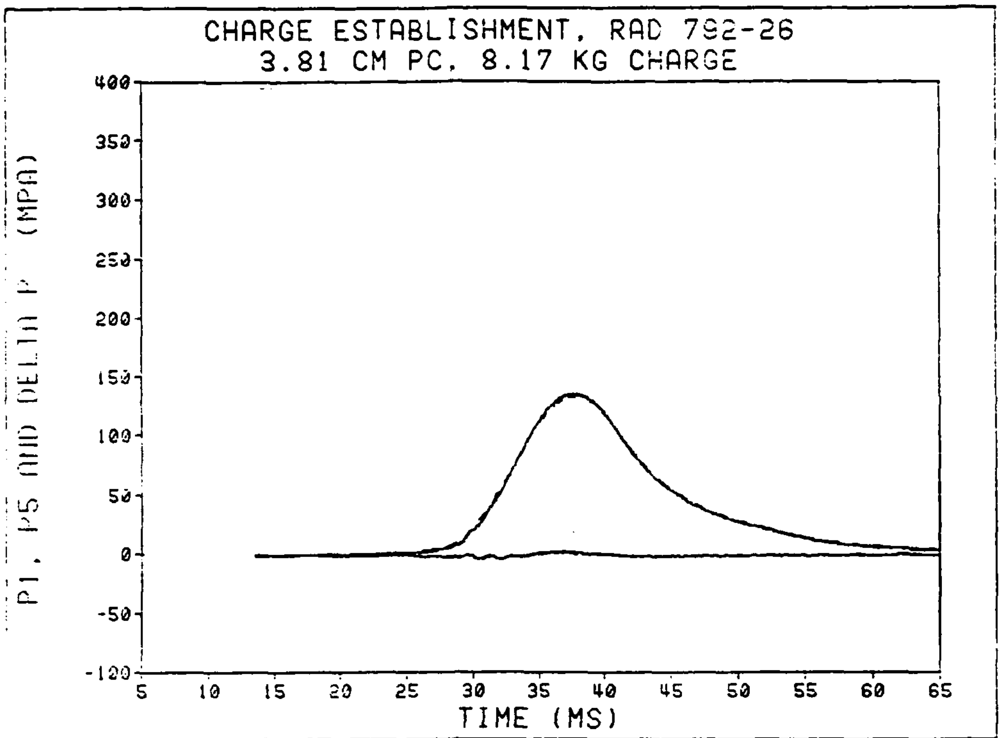

TEST ROUND, RAD 792-28
30.0 CM PC, 9.75 KG CHARGE
NO PS, THEREFORE NO DELTA P
P1 (MPA)
TIME (MS)

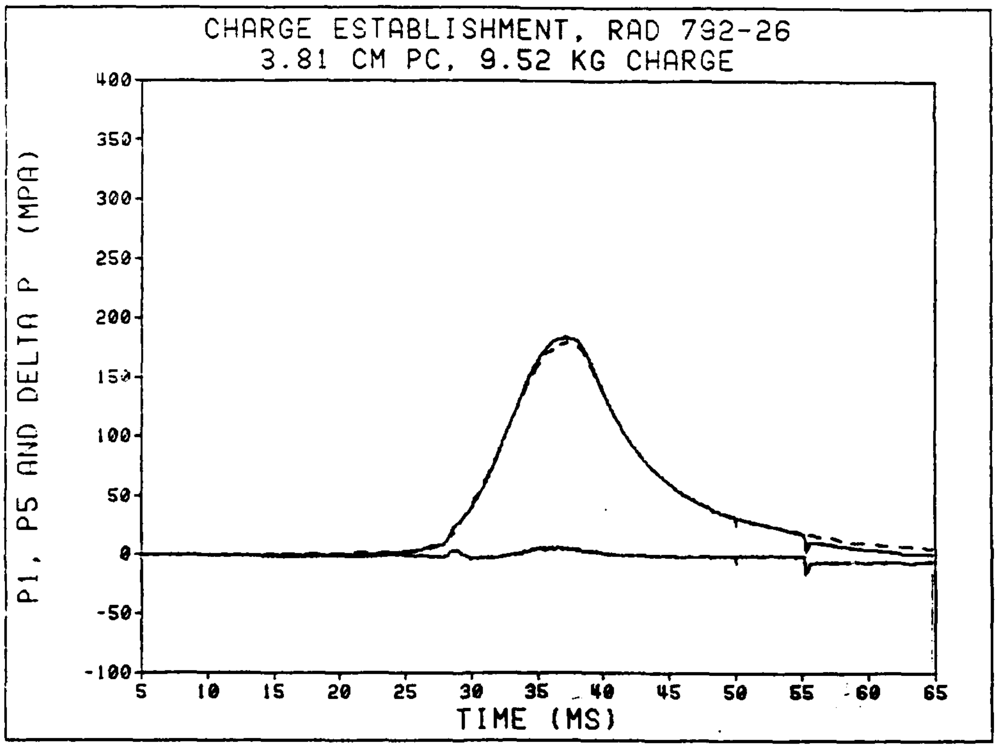


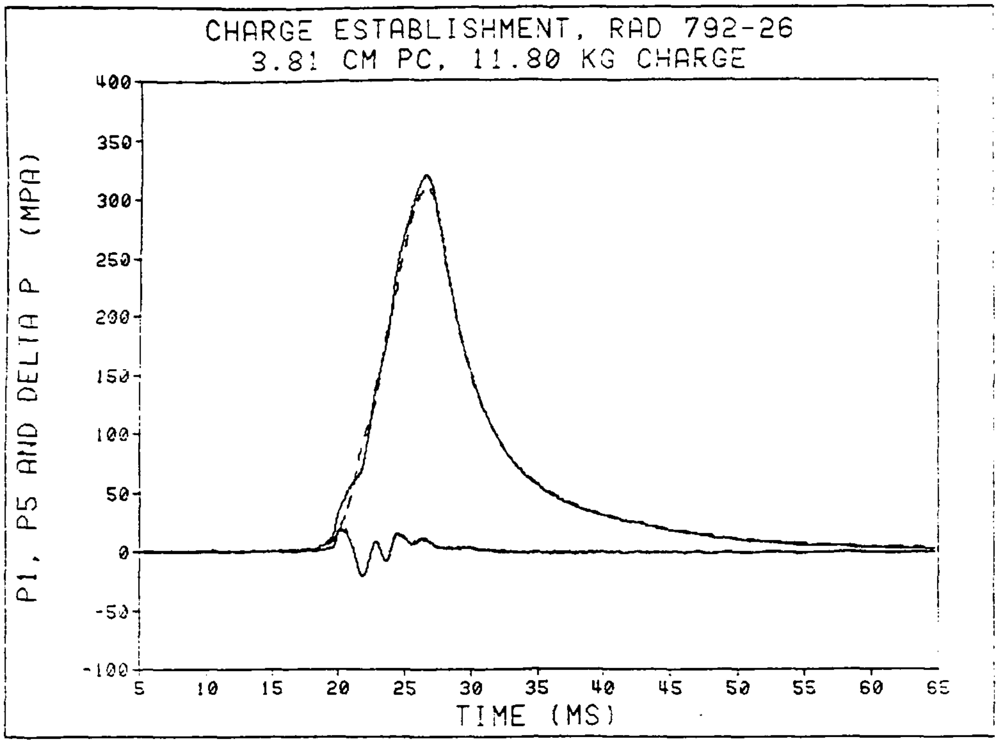
M203
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
35 40 45 50 55 60 65 70 75 80 85 90 95
TIME (MS)



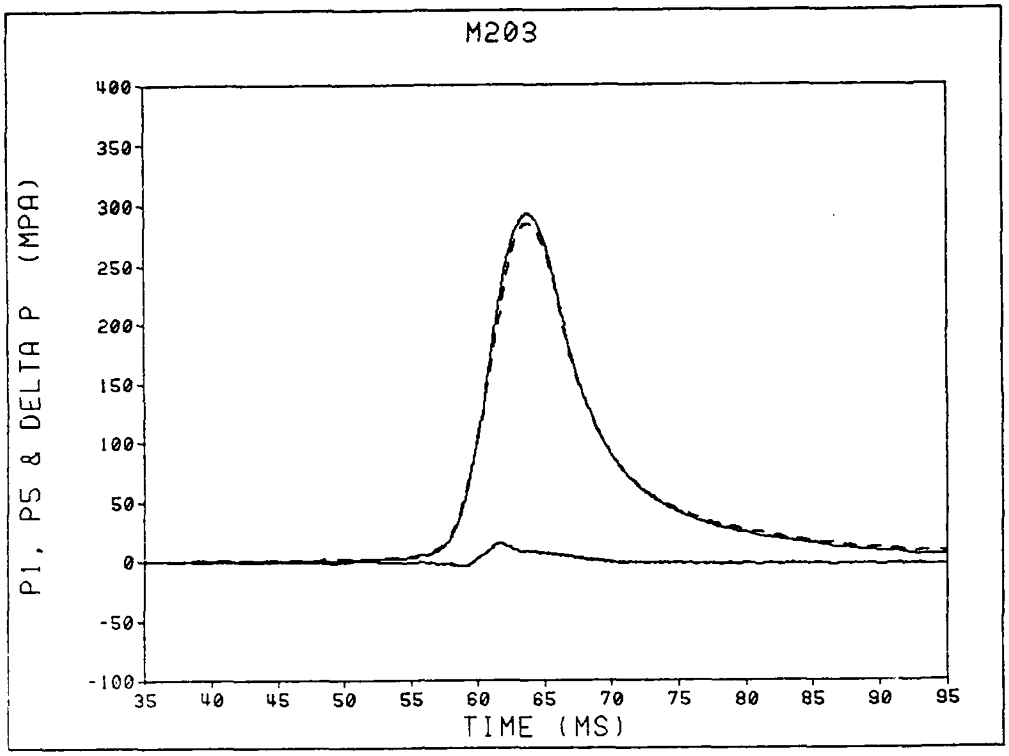
M203
P1, P5 & DELTA P (MPA)
400
350
300
250
200
150
100
50
0
-50
-100
35 40 45 50 55 60 65 70 75 80 85 90 95
TIME (MS)

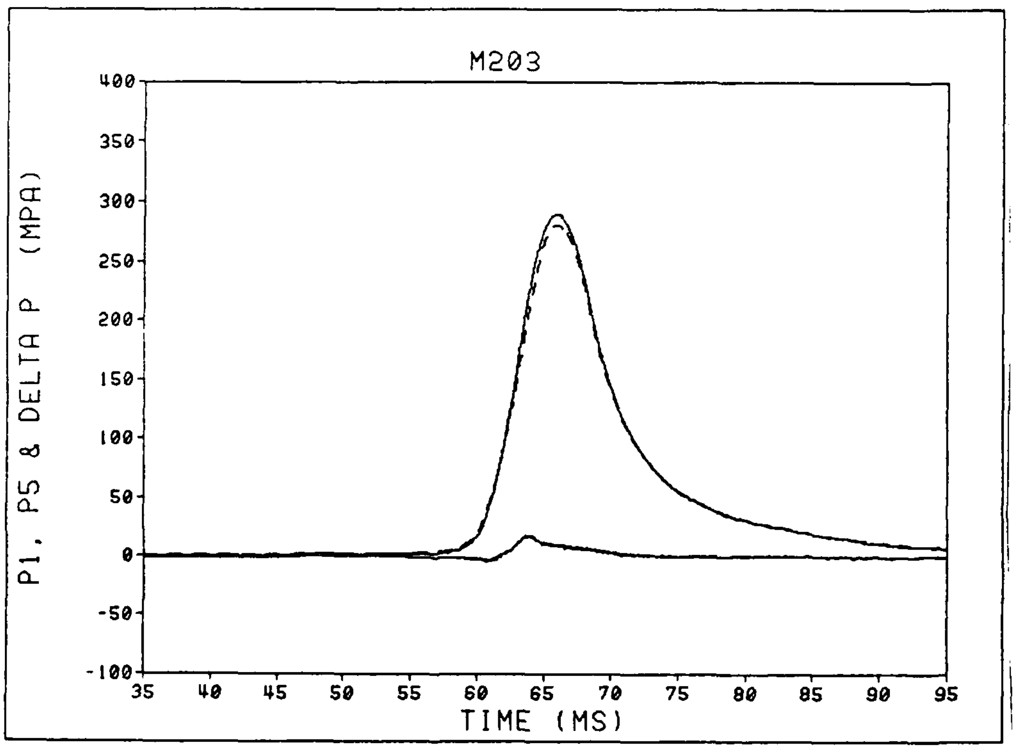

CHARGE ESTABLISHMENT, RAD 792-26
3.81 CM PC, 8.17 KG CHARGE
P1, P5 AND DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

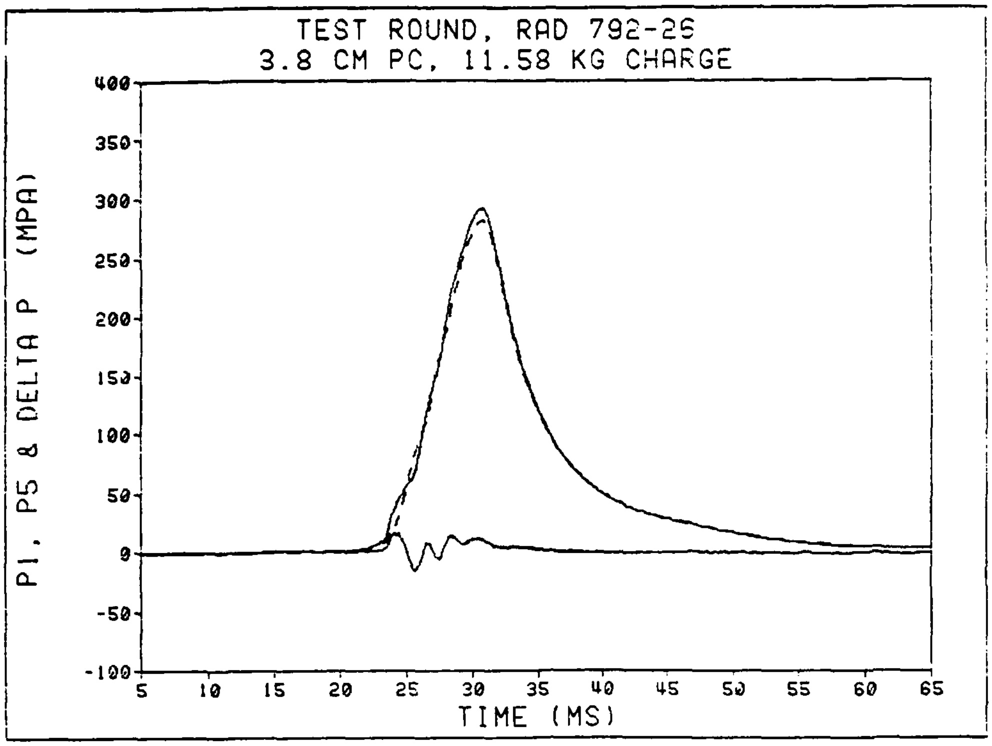

CHARGE ESTABLISHMENT, RAD 792-26
3.81 CM PC, 9.52 KG CHARGE
P1, P5 AND DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

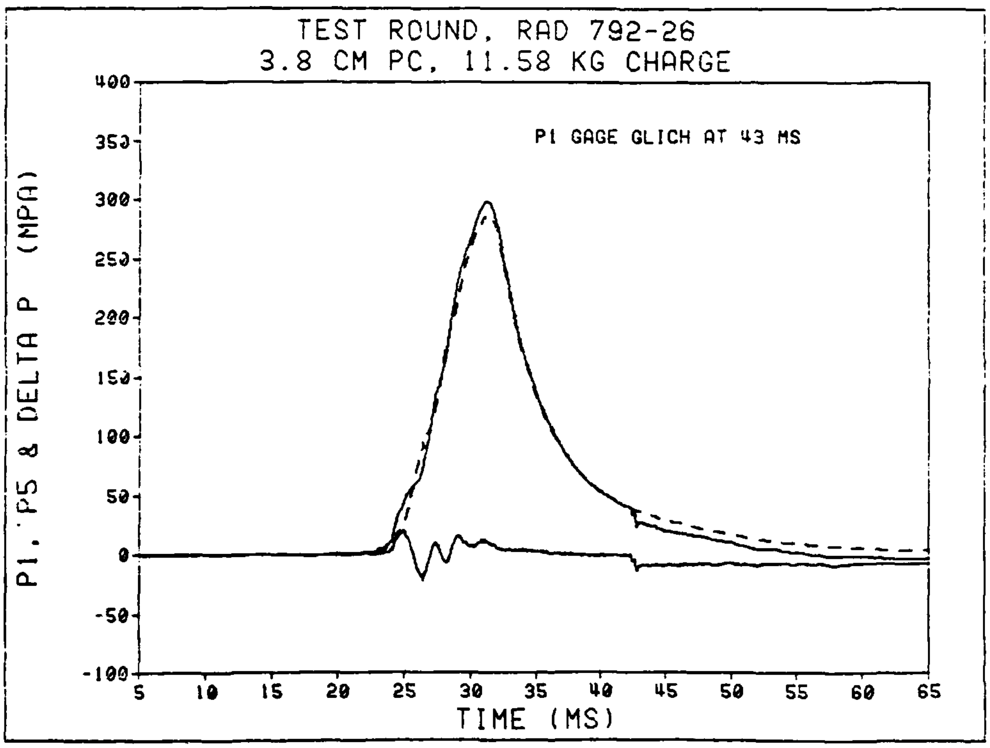


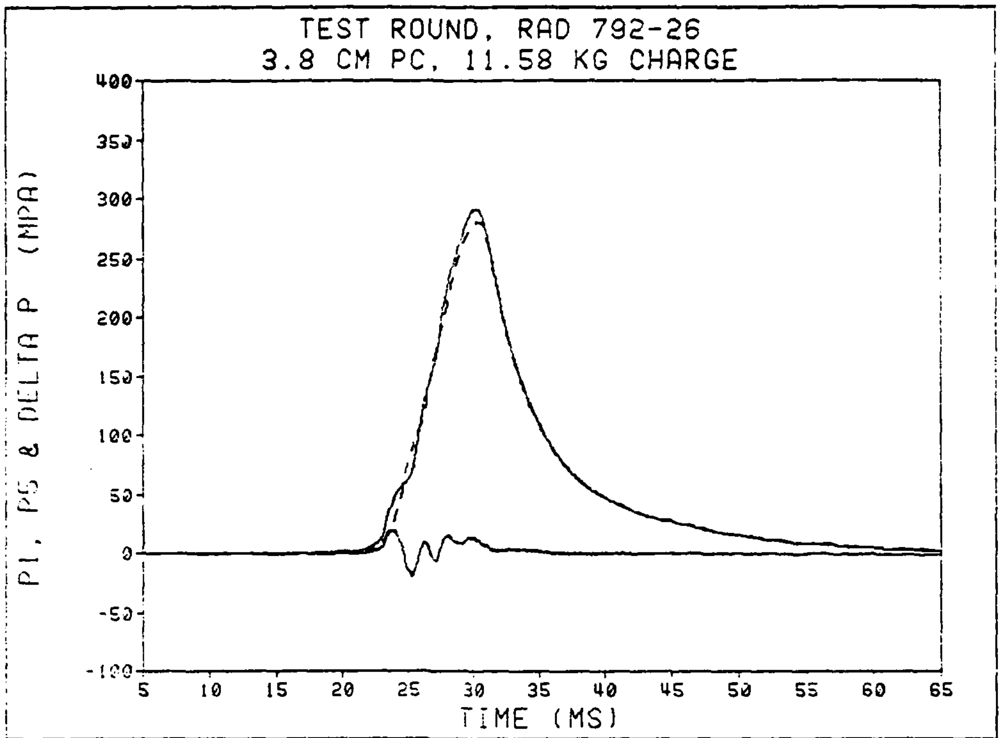
CHARGE ESTABLISHMENT, RAD 792-26
3.81 CM PC, 11.80 KG CHARGE
P1, P5 AND DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

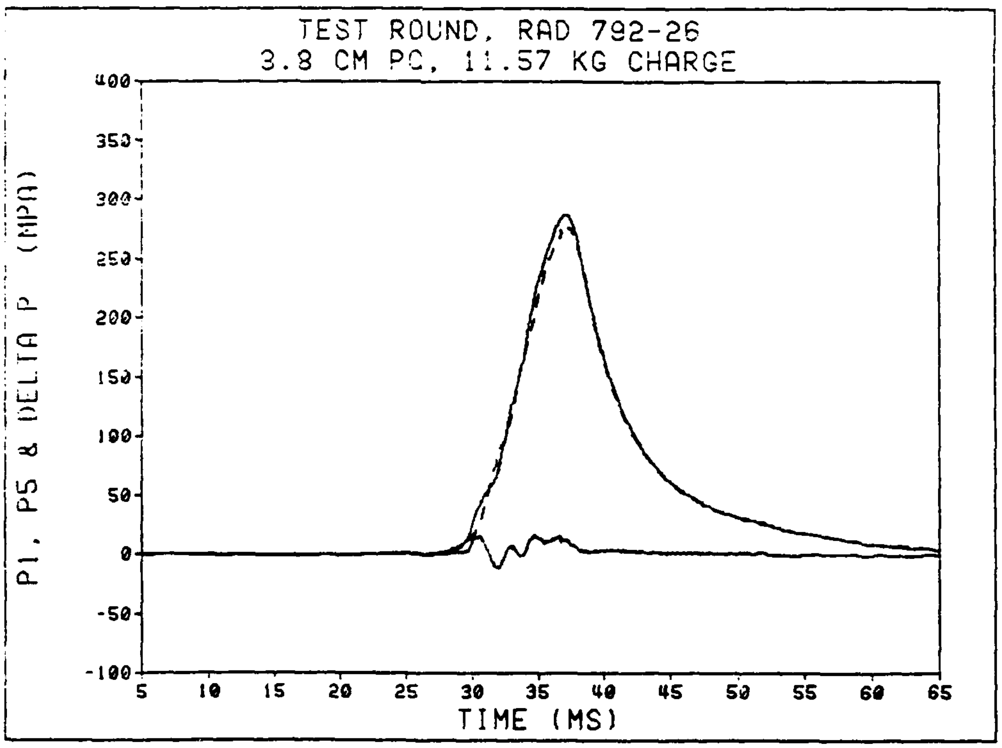

M203
P1, P5 & DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
35
40
45
50
55
60
65
70
75
80
85
90
95

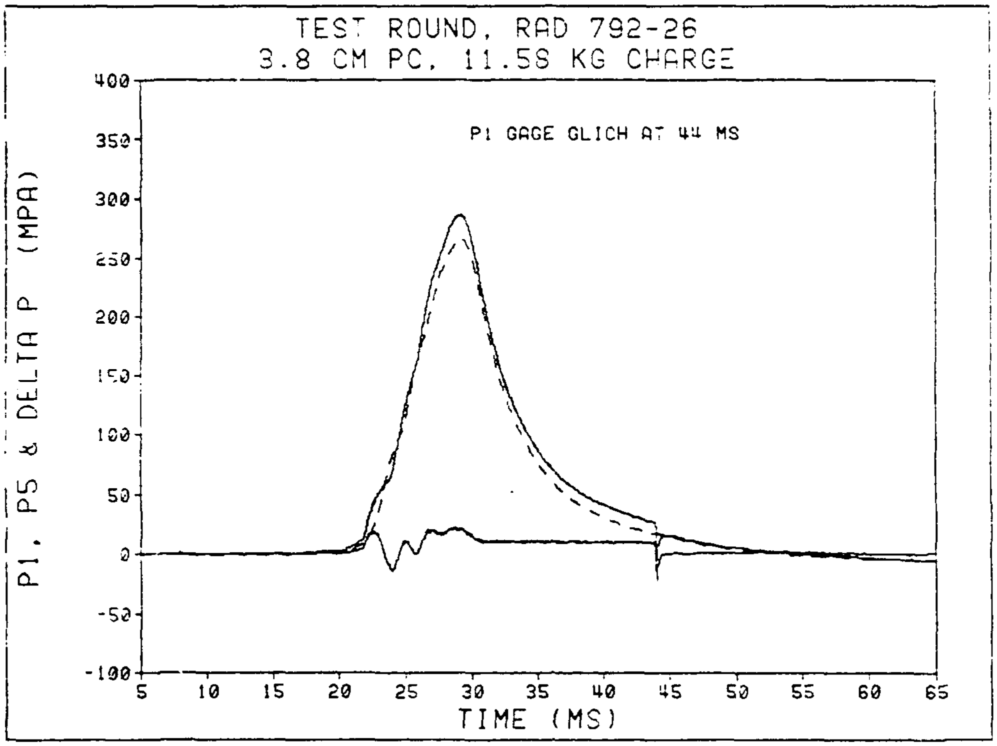

M203
P1, P5 & DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
35
40
45
50
55
60
65
70
75
80
85
90
95

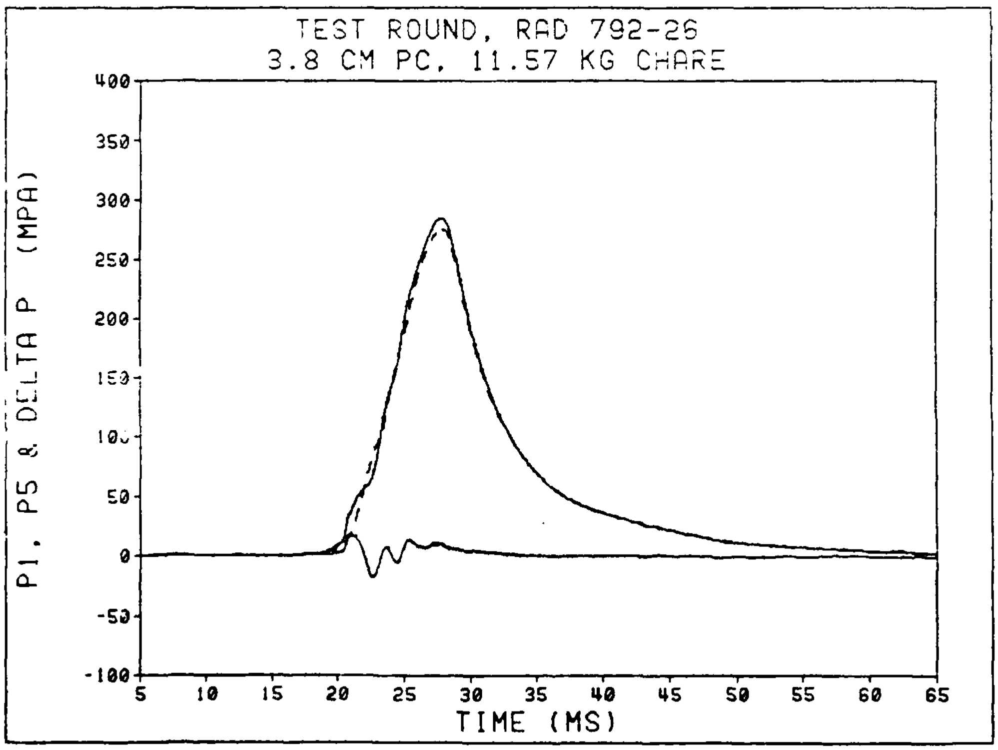

TEST ROUND, RAD 792-25
3.8 CM PC, 11.58 KG CHARGE
P1, P5 & DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

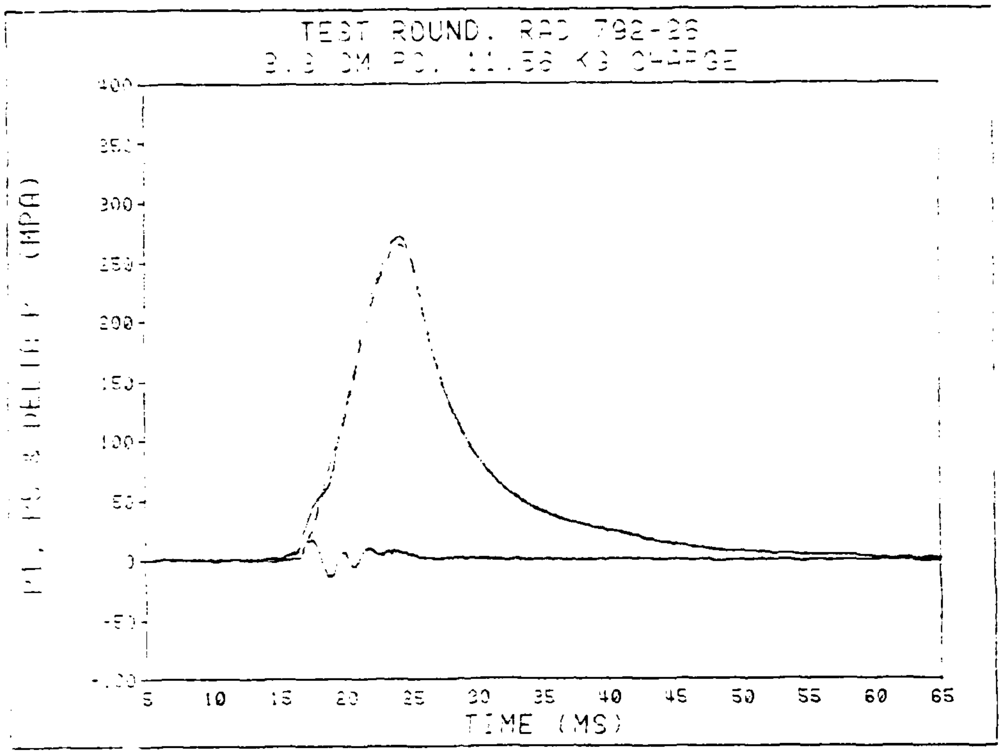

TEST ROUND, RAD 792-26
3.8 CM PC, 11.58 KG CHARGE
P1 GAGE GLICH AT 43 MS
P1, P5 & DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

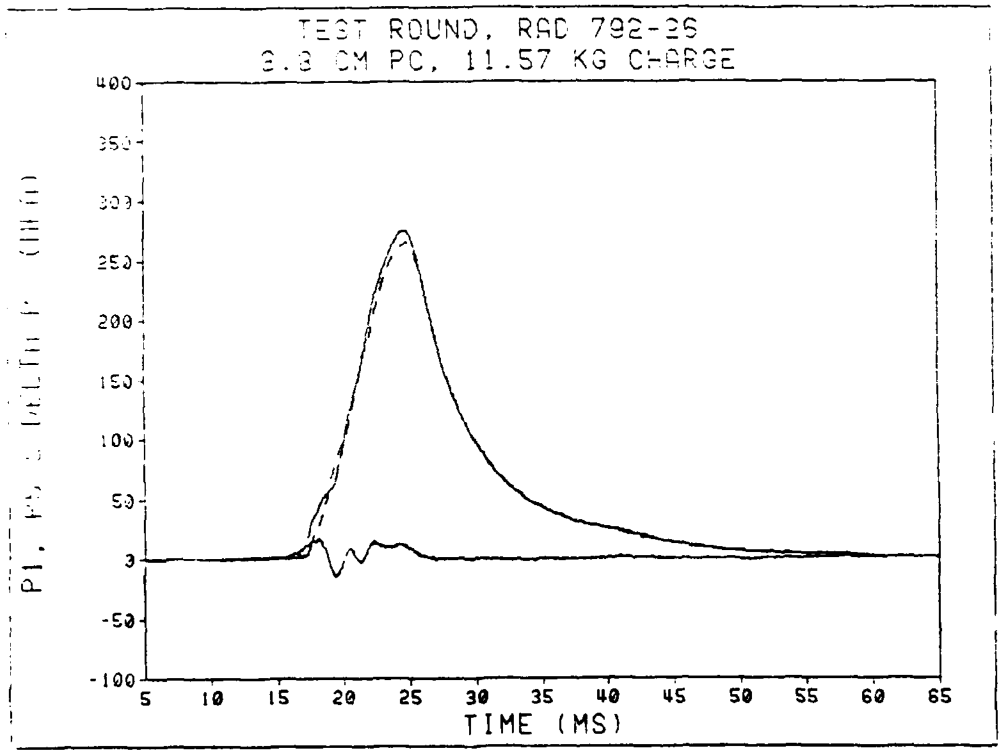

TEST ROUND, RAD 792-26
3.8 CM PC, 11.58 KG CHARGE
P1, P5 & DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

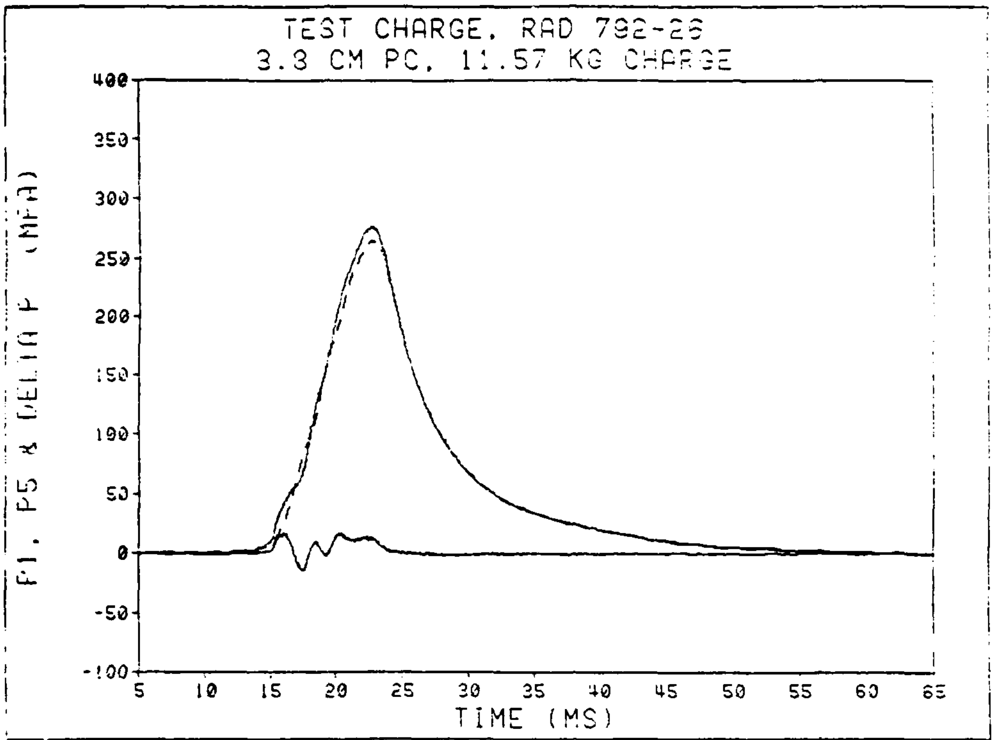

TEST ROUND, RAD 792-26
3.8 CM PC, 11.57 KG CHARGE
P1, P5 & DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65


TEST ROUND, RAD 792-26
3.8 CM PC, 11.58 KG CHARGE
P1 GAGE GLICH AT 44 MS
P1, P5 & DELTA P (MPA)
TIME (MS)


TEST ROUND, RAD 792-26
3.8 CM PC, 11.57 KG CHARE
P1, P5 & DELTA P (MPA)
TIME (MS)


TEST ROUND, RAD 792-26
TIME (MS)


TEST ROUND, RAD 792-26
3.8 CM PC, 11.57 KG CHARGE
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65
TIME (MS)



TEST CHARGE, RAD 792-26
3.3 CM PC, 11.57 KG CHARGE
P1, P5 & DELTA P (MPA)
TIME (MS)
400
350
300
250
200
150
100
50
0
-50
-100
5
10
15
20
25
30
35
40
45
50
55
60
65

No of Copies	Organization
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	HQDA (SARD-TR) WASH DC 20310-0001
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Laboratory Command ATTN: AMSLC-DL Adelphi, MD 20783-1145
2	Commander US Army, ARDEC ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000
2	Commander US Army, ARDEC ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory US Army, ARDEC ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050
1	Commander US Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299-5000
1	Director US Army Aviation Research and Technology Activity ATTN: SAVRT-R (Library) M/S 219-3 Ames Research Center Moffett Field, CA 94035-1000

No of Copies	Organization
1	Commander US Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander US Army Tank-Automotive Command ATTN: AMSTA-TSL (Technical Library) Warren, MI 48397-5000
1	Director US Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
(Class. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660
1	Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000
	Aberdeen Proving Ground
2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Cdr, USATECOM ATTN: AMSTE-TD
3	Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-MSI
1	Dir, VLAMO ATTN: AMSLC-VL-D

No. of Copies	Organization
1	Commander USA Concepts Analysis Agency ATTN: D. Hardison 8120 Woodmont Avenue Bethesda, MD 20014-2797
1	C.I.A. 01R/DB/Standard Washington, DC 20505
1	US Army Ballistic Missile Defense Systems Command Advanced Technology Center P.O. Box 1500 Huntsville, AL 35807-3801
1	Chairman DoD Explosives Safety Board Room 856-C Hoffman Bldg. 1 2461 Eisenhower Avenue Alexandria, VA 22331-0600
1	Commander US Army Materiel Command ATTN: AMCPM-GCM-WF 5001 Eisenhower Avenue Alexandria, VA 22333-5001
1	Commander US Army Materiel Command ATTN: AMCDE-DW 5001 Eisenhower Avenue Alexandria, VA 22333-5001
3	Project Manager Autonomous Precision-Guided Munition (APGM) US Army, ARDEC ATTN: AMCPM-CW AMCPM-CWW AMCPM-CWA-S, R. DeKleine Picatinny Arsenal, NJ 07806-5000
2	Project Manager Production Base Modernization Agency ATTN: AMSMC-PBM, A. Siklosi AMSMC-PBM-E, L. Laibson Picatinny Arsenal, NJ 07806-5000

No. of Copies	Organization
3	PEO-Armaments Project Manger Tank Main Armament Systems ATTN: AMCPM-TMA, K. Russell AMCPM-TMA-105 AMCPM-TMA-120, C. Roller Picatinny Arsenal, NJ 07806-5000
1	Commander US Army, ARDEC ATTN: SMCAR-AEE Picatinny Arsenal, NJ 07806-5000
13	Commander US Army, ARDEC ATTN: SMCAR-AEE-B, A. Beardell S. Bernstein P. Bostonian B. Brodman R. Cirincione D. Downs S. Einstein A. Grabowsky P. Hui J. O'Reilly N. Ross J. Rutkowski S. Westley Picatinny Arsenal, NJ 07806-5000
2	Commander US Army, ARDEC ATTN: SMCAR-AES, S. Kaplowitz D. Spring Picatinny Arsenal, NJ 07806-5000
2	Commander US Army, ARDEC ATTN: SMCAR-HFM, E. Barrieres SMCAR-CCH-V, C. Mandala Picatinny Arsenal, NJ 07806-5000
1	Commander US Army, ARDEC ATTN: SMCAR-FSA-T M. Salsbury Picatinny Arsenal, NJ 07806-5000
1	Commander, USACECOM R&D Technical Library ATTN: ASQNC-ELC-I-T, Myer Center Fort Monmouth, NJ 07703-5301

No. of Copies	Organization
1	Commander US Army Harry Diamond Laboratories ATTN: SLCHD-TA-L 2800 Powder Mill Rd Adelphi, MD 20783-1145
1	Commandant US Army Aviation School ATTN: Aviation Agency Fort Rucker, AL 36360
1	Project Manager US Army Tank-Automotive Command Improved TOW Vehicle ATTN: AMCPM-ITV Warren, MI 48397-5000
2	Program Manager US Army Tank-Automotive Command ATTN: AMCPM-ABMS, T. Dean (2 cys) Warren, MI 48092-2498
1	Project Manager US Army Tank-Automotive Command Fighting Vehicle Systems ATTN: AMCPM-BFVS Warren, MI 48092-2498
1	President US Army Armor and Engineer Board ATTN: ATZK-AD-S Fort Knox, KY 40121-5200
1	Project Manager US Army Tank-Automotive Command M-60 Tank Development ATTN: AMCPM-ABMS Warren, MI 48092-2498
1	Director HQ, TRAC RPD ATTN: ATCD-MA Fort Monroe, VA 23651-5143
2	Director US Army Materials Technology Laboratory ATTN. SLCMT-ATL (2 cys) Watertown, MA 02172-0001

No. of Copies	Organization
1	Commander US Army Research Office ATTN: Technical Library P.O. Box 12211 Research Triangle Park, NC 27709-2211
1	Commander US Army Belvoir Research and Development Center ATTN: STRBE-WC Fort Belvoir, VA 22060-5006
1	Director US Army TRAC-Ft. Lee ATTN: ATRC-L, Mr. Cameron Fort Lee, VA 23801-6140
1	Commandant US Army Command and General Staff College Fort Leavenworth, KS 66027
1	Commandant US Army Special Warfare School ATTN: Rev and Trng Lit Div Fort Bragg, NC 28307
3	Commander Radford Army Ammunition Plant ATTN: SMCAR-QA/HI LIB (3 cys) Radford, VA 24141-0298
1	Commander US Army Foreign Science and Technology Center ATTN: AMXST-MC-3 220 Seventh Street, NE Charlottesville, VA 22901-5396
2	Commander Naval Sea Systems Command ATTN: SEA 62R SEA 64 Washington, DC 20362-5101
1	Commander Naval Air Systems Command ATTN: AIR-954-Technical Library Washington, DC 20360

No. of Copies	Organization
1	Assistant Secretary of the Navy (R, E, and S) ATTN: R. Reichenbach Room 5E787 Pentagon Bldg Washington, DC 20375
1	Naval Research Laboratory Technical Library Washington, DC 20375
1	Commandant US Army Command and General Staff College Fort Leavenworth, KS 66027
2	Commandant US Army Field Artillery Center and School ATTN: ATSF-CO-MW, E. Dublisky (2 cys) Fort Sill, OK 73503-5600
1	Office of Naval Research ATTN: Code 473, R. S. Miller 800 N. Quincy Street Arlington, VA 22217-9999
3	Commandant US Army Armor School ATTN: ATZK-CD-MS, M. Falkovitch (3 cys) Armor Agency Fort Knox, KY 40121-5215
2	Commander US Naval Surface Warfare Center ATTN: J. P. Consaga C. Gotzmer Indian Head, MD 20640-5000
4	Commander Naval Surface Warfare Center ATTN: Code 240, S. Jacobs Code 730 Code R-13, K. Kim R. Bernecker Silver Spring, MD 20903-5000
2	Commanding Officer Naval Underwater Systems Center ATTN: Code 5B331, R. S. Lazar Technical Library Newport, RI 02840

No. of Copies	Organization
5	Commander Naval Surface Warfare Center ATTN: Code G33, J. L. East W. Burrell J. Johndrow Code G23, D. McClure Code DX-21 Technical Library Dahlgren, VA 22448-5000
3	Commander Naval Weapons Center ATTN: Code 388, C. F. Price Code 3895, T. Parr Information Science Division China Lake, CA 93555-6001
1	OSD/SDIO/IST ATTN: Dr. H. Caveny Pentagon Washington, DC 20301-7100
3	Commander Naval Ordnance Station ATTN: T. C. Smith D. Brooks Technical Library Indian Head, MD 20640-5000
1	AL/TSTL (Technical Library) ATTN: J. Lamb Edwards AFB, CA 93523-5000
1	AFATL/DLYV Eglin AFB, FL 32542-5000
1	AFATL/DLXP Eglin AFB, FL 32542-5000
1	AFATL/DLJE Eglin AFB, FL 32542-5000
1	NASA/Lyndon B. Johnson Space Center ATTN: NHS-22 Library Section Houston, TX 77054
1	AFELM, The Rand Corporation ATTN: Library D 1700 Main Street Santa Monica, CA 90401-3297

No. of Copies	Organization
3	AAI Corporation ATTN: J. Herbert J. Frankle D. Cleveland P.O. Box 126 Hunt Valley, MD 21030-0126
2	Aerojet Solid Propulsion Company ATTN: P. Micheli L. Torreyson Sacramento, CA 96813
1	Atlantic Research Corporation ATTN: M. King 5390 Cherokee Avenue Alexandria, VA 22312-2302
3	AL/LSCF ATTN: J. Levine L. Quinn T. Edwards Edwards AFB, CA 93523-5000
1	AVCO Everett Research Laboratory ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149-5936
2	Calspan Corporation ATTN: C. Murphy (2 cys) P.O. Box 400 Buffalo, NY 14225-0400
1	General Electric Company Armament Systems Department ATTN: J. Mandzy 128 Lakeside Avenue Burlington, VT 05401-4985
1	IITRI ATTN: M. J. Klein 10 W. 35th Street Chicago, IL 60616-3799
1	Hercules, Inc. Allegheny Ballistics Laboratory ATTN: William B. Walkup P.O. Box 210 Rocket Center, WV 26726
1	Hercules, Inc. Radford Army Ammunition Plant ATTN: E. Hibshman Radford, VA 24141-0299

No. of Copies	Organization
3	Lawrence Livermore National Laboratory ATTN: L-355, A. Buckingham M. Finger L-324, M. Constantino P.O. Box 808 Livermore, CA 94550-0622
1	Olin Corporation Badger Army Ammunition Plant ATTN: F. E. Wolf Baraboo, WI 53913
2	Olin Corporation Smokeless Powder Operation ATTN: E. J. Kirschke A. F. Gonzalez P.O. Box 222 St. Marks, FL 32355-0222
1	Paul Gough Associates, Inc. ATTN: Dr. Paul S. Gough 1048 South Street Portsmouth, NH 03801-5423
1	Physics International Company ATTN: Library, H. Wayne Wampler 2700 Merced Street San Leandro, CA 98457-5602
1	Princeton Combustion Research Laboratory, Inc. ATTN: M. Summerfield 475 US Highway One Monmouth Junction, NJ 08852-9650
2	Rockwell International Rocketdyne Division ATTN: BA08, J.E. Flanagan J. Gray 6633 Canoga Avenue Canoga Park, CA 91303-2703
3	Thiokol Corporation Huntsville Division ATTN: D. Flanigan Dr. John Deur Technical Library Huntsville, AL 35807

No. of Copies	Organization
2	Thiokol Corporation Elkton Division ATTN: R. Biddle Technical Library P.O. Box 241 Elkton, MD 21921-0241
1	Veritay Technology, Inc. ATTN: E. Fisher 4845 Millersport Highway East Amherst, NY 14501-0305
1	Universal Propulsion Company ATTN: H. J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 84029
1	Battelle Memorial Institute ATTN: Technical Library 505 King Avenue Columbus, OH 43201-2693
1	Brigham Young University Department of Chemical Engineering ATTN: M. Beckstead Provo, UT 84601
1	California Institute of Technology 204 Karman Laboratory Main Stop 301-46 ATTN: F.E.C. Culick 1201 E. California Street Pasadena, CA 91109
1	California Institute of Technology Jet Propulsion Laboratory ATTN: L. D. Strand, MS 512/102 4800 Oak Grove Drive Pasadena, CA 91109-8099
1	University of Illinois Department of Mechanical/Industrial Engineering ATTN: H. Krier 144 MEB; 1206 N. Green Street Urbana, IL 61801-2978
1	University of Massachusetts Department of Mechanical Engineering ATTN: K. Jakus Amherst, MA 01002-0014

No. of Copies	Organization
1	University of Minnesota Department of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55414-3368
3	Georgia Institute of Technology School of Aerospace Engineering ATTN: B.T. Zim E. Price W.C. Strahle Atlanta, GA 30332
1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616-3896
1	Johns Hopkins University Applied Physics Laboratory Chemical Propulsion Information Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20707-0690
1	Massachusetts Institute of Technology Department of Mechanical Engineering ATTN: T. Toong 77 Massachusetts Avenue Cambridge, MA 02139-4307
1	Pennsylvania State University Applied Research Laboratory ATTN: G. M. Faeth University Park, PA 16802-7501
1	Pennsylvania State University Department of Mechanical Engineering ATTN: K. Kuo University Park, PA 16802-7501
1	Purdue University School of Mechanical Engineering ATTN: J. R. Osborn TSPC Chaffee Hall West Lafayette, IN 47907-1199
1	SRI International Propulsion Sciences Division ATTN: Technical Library 333 Ravenwood Avenue Menlo Park, CA 94025-3493

No. of Copies	Organization
1	Rensselaer Ploytechnic Institute Department of Mathematics Troy, NY 12181
2	Director Los Alamos Scientific Laboratory ATTN: T3, D. Butler M. Division, B. Craig P.O. Box 1663 Los Alamos, NM 87544
1	General Applied Sciences Laboratory ATTN: J. Erdos 77 Raynor Avenue Ronkonkama, NY 11779-6649
1	Battelle PNL ATTN: Mr. Mark Garnich P.O. Box 999 Richland, WA 99352
1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Castle Point Station Hoboken, NJ 07030-5907
1	Rutgers University Department of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903
1	University of Southern California Mechanical Engineering Department ATTN: 0HE200, M. Gerstein Los Angeles, CA 90089-5199
2	University of Utah Department of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112-1194
1	Washington State University Department of Mechanical Engineering ATTN: C. T. Crowe Pullman, WA 99163-5201

No. of Copies	Organization
1	Honeywell, Inc. ATTN: R. E. Tompkins MN38-3300 10400 Yellow Circle Drive Minnetonka, MN 55343
1	Science Applications, Inc. ATTN: R. B. Edelman 23146 Cumorah Crest Drive Woodland Hills, CA 91364-3710
1	Battelle Columbus Laboratories ATTN: Mr. Victor Levin 505 King Avenue Columbus, OH 43201-2693
1	Allegheny Ballistics Laboratory Propulsion Technology Department Hercules Aerospace Company ATTN: Mr. Thomas F. Farabaugh P.O. Box 210 Rocket Center, WV 26726
1	MBR Research Inc. ATTN: Dr. Moshe Ben-Reuven 601 Ewing St., Suite C-22 Princeton, NJ 08540
	Aberdeen Proving Ground
	Cdr, CSTA ATTN: STECS-LI, R. Hendricksen

INTENTIONALLY LEFT BLANK.

USER EVALUATION SHEET/CHANGE OF ADDRESS

This laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers below will aid us in our efforts.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______________________________

2. How, specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.) ______________________________

3. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______________________________

4. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______________________________

BRL Report Number BRL-TR-3189 Division Symbol ______________

Check here if desire to be removed from distribution list. ____

Check here for address change. ____

Current address: Organization ______________________________
Address ______________________________

DEPARTMENT OF THE ARMY

OFFICIAL BUSINESS

BUSINESS REPLY MAIL
FIRST CLASS PERMIT No 0001, APG, MD

Postage will be paid by addressee.

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES